6 Proceedings

WHEY PRODUCTS CONFERENCE

held at Chicago, Illinois
October 25-26, 1984
and sponsored jointly by
The Whey Products Institute
and
The U.S. Department of Agriculture

AGRICULTURAL RESEARCH SERVICE • U.S. DEPARTMENT OF AGRICULTURE

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Agricultural Research Service
Eastern Regional Research Center
Philadelphia, PA 19118

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1984 Whey Products Conference

Co-sponsored by:

Whey Products Institute U.S. Department of Agriculture

October 25-26, 1984
Chicago O'Hare Marriott Hotel
8535 West Higgins Road
Chicago, Illinois

PROGRAM

Friday, October 26

Session III. Technology
Chairman: L. Kull

WELCOMING REMARKS

H. Jack Pollei
President, Whey Products Institute
Galloway West Company

John H. Woychik
Chief, Food Science Laboratory
USDA, Eastern Regional Research Center
Philadelphia, PA 19118

Mr. Pollei

It is my pleasure to be serving as President of the Whey Products Institute, which with the U.S. Department of Agriculture sponsors these biennial Whey Products Conferences. Based upon Conference preregistration figures and the number of persons in the room this morning, there is no question but that this series of Conferences is meaningful and fulfills an industry need. The program for the 1984 Conference was developed by the Whey Products Institute staff, and your attendance here this morning tells them that their untiring efforts in preparing for the Conference were both worthwhile and appreciated.

I am impressed both with the wide range of subjects to be presented at this Conference and with the outstanding caliber of participating speakers. Therefore, to each speaker and session chairman as well as to our Institute staff, may I express my sincere appreciation for your efforts to make this one of the most successful conferences to date. And as an attendee, as each of us is, I look forward to active participation in the industry discussions, for these add even more to the value of a program such as this.

Today, I believe that we are at the threshold of one of the most uncertain periods faced by the whey processing industry since the Whey Products Institute was organized in 1971. However, while uncertainty about the future quite naturally and normally causes apprehension, it also affords us the opportunity to move forward in a positive manner to meet the challenges ahead.

While many in the dairy industry look to commodity products such as whey and to the whey processing industry as being somewhat in a shadow when compared to the processing and distribution of fluid milk and other better-known dairy products, I must remind them of the progress our industry has made during its first decade. And now with but a foot into our second decade, I challenge these industry skeptics to match the excitement brought about by the extremely rapid rate of technological development now a part of our industry. It is on the basis of these developments that the outlook for our industry is so positive!

Your interest in this Conference acknowledges the importance of our industry today, and I trust you concur that as our industry continues to advance, it has a bright future. I don't know any of the specifics of what my colleague, Don Storhoff, will share with you in his remarks at the banquet this evening,

but I am certain his outlook for our industry will be equally as positive as mine, and I, too, look forward to his remarks.

Dr. Woychik

It is a pleasure for me to join with Jack Pollei in welcoming you to the Eighth Whey Products Conference on behalf of the Department of Agriculture and Dr. John P. Cherry, Director of the Eastern Regional Research Center.

The program prepared for these two days will give you the opportunity to hear presentations by members of your industry, by others in related fields, and by academic and institutional scientists. But most of all, the accumulated experience and expertise that resides in each of you collectively represents a critical mass of whey knowledge not often assembled under one roof. I hope that with the stimulation provided by our speakers and by your individual interactions, you will all leave with renewed vigor to meet the challenge of increasing whey utilization and profitability.

Welcome to the Whey Products Conference.

RESIDUAL MILK CLOTTING ENZYMES

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ABSTRACT

Ten commercial milk coagulants were used to produce Cheddar cheese wheys. Wheys were then concentrated fourfold by ultrafiltration following pasteurization, separation, and prewarming. Fluxes were monitored. Wheys, final concentrates, and pooled permeates were tested for total nitrogen, nonprotein nitrogen and fat. Wheys and concentrates were also tested for residual milk clotting activity. Residual activity was observed in the wheys and concentrates originating from the unmodified proteases of Mucor miehei and Mucor pusillus, but not from the two modified proteases of Mucor miehei, an Endothia parasitica protease, two bovine pepsins, a bovine pepsin-swine pepsin blend, or calf rennet which served as the control. No significant differences in flux or nitrogen yields were observed.

INTRODUCTION

The application of ultrafiltration in whey processing has increased dramatically in recent years (1, 2). Ultrafiltration permits the whey processor to produce whey protein concentrates with increased marketability and uses. These concentrates have found wide application in such foods as ice cream, flavored beverages, bakery goods, and infant foods (3).

In some of these applications, especially ice cream and infant foods (11), problems have occurred because proteolytic enzymes used in the cheesemaking process have carried over into the protein concentrate.

The enzyme most commonly associated with these problems has been that produced by Mucor miehei. As a result, enzyme manufacturers have modified this enzyme to make it less heat resistant and, hence, more susceptible to inactivation (7). A number of these modified enzymes are now on the market. However, the published literature contains little information on the conditions needed to inactivate these modified enzymes (6).

In addition, there have been reports that some milk-clotting enzymes have an effect on ultrafiltration flux and nitrogen recovery in the whey protein concentrates.

The purpose of this study was to investigate: 1) residual enzyme activity in whey and whey protein concentrates, and 2) the effect of various milk coagulants on ultrafiltration flux and nitrogen recovery in the whey protein concentrates.

MATERIALS AND METHODS

Milk Coagulants

Milk coagulants were obtained from commercial suppliers and examined in random order. Investigated coagulants included: two bovine pepsins (BPa and BPb), a 65:35 mixture of bovine pepsin and swine pepsin (BP/SP), a blend of bovine pepsin and Mucor pusillus protease (BP/MP), a Mucor miehei protease (MM), two modified Mucor miehei proteases (MMM_a and MMM_b), a Mucor pusillus protease (MP), an Endothia parasitica protease (EP), and calf rennet (CR), which served as the control.

Whey Production and Pretreatments

Pasteurized (63°C/30 min) whole milks (205 kg) were cooled to 31°C, inoculated with 32.5 ml of a direct-vat-set lactic culture and incubated for 1 hr. Milk coagulants were added at a rate (65 ml coagulant/205 kg milk) that delivered firm coagula after 25-30 min. Coagulated milks were cut with .95-cm wire knives, heated to 39°C over a 30-min period, and held at that temperature for 1 hr before draining.

At draining, wheys were pumped through an in-line filter (178 μm wire mesh), pasteurized (63°C/30 min) within 40 min, held (57°C/30 min), and separated (DeLaval Model 618). The separated wheys were cooled to 16°C, placed in a 7°C cold room, stored overnight, and heated to 57°C for 30 min prior to ultrafiltration.

Preliminary work demonstrated that this treatment was necessary to obtain reproducible results from duplicate whey samples obtained with any single coagulant. Unless cheesemaking and processing conditions were rigidly controlled, there were greater flux and yield variations between duplicates from a single coagulant than between wheys from dissimilar coagulants.

Ultrafiltration

Prewarmed wheys (120 kg) were concentrated on a Dorr Oliver series "S" ultrafiltration unit. The unit contained a 1.405 m^2 polysulfone membrane with a molecular weight cut-off of 30,000. Operating conditions were 56 ± 1°C and inlet/outlet pressures of 3.2/1.3 kg/cm^2, respectively. Wheys were concentrated until 75% of the initial feed weight had been removed as permeate.

Sampling and Analyses

Duplicate flux measurements were taken at 0%, 25%, 50%, and 75% weight reductions after the system had been operating at steady state (permeate stream returned to feed tank) for 5 min. Milks, wheys, final concentrates, and pooled permeates were tested for total nitrogen, nonprotein nitrogen, and fat. Wheys and concentrates also were tested for residual enzyme activity. All analyses were performed in duplicate using reagent-grade chemicals and distilled water.

Residual enzyme activity was determined by the method of Holmes et al. (8) which had a detection limit of 1×10^{-4} rennet units/ml. Total nitrogen (TN) was determined by a macro-Kjeldahl method (5). Nonprotein nitrogen (NPN) was measured as nitrogen soluble in 12% trichloroacetic acid. True protein was calculated as 6.38 X (%TN - %NPN). Fat was determined by the Mojonnier ether-extraction method (10). Statistical treatment was by ANOVA, $p = .05$ (4).

RESULTS AND DISCUSSION

Initial Trials and Observations

Initial experiments involved the ultrafiltration of coagulant-treated wheys rather than coagulant-produced wheys. Pasteurized separated Cheddar cheese wheys (pH 6.0-6.2) were inoculated with a coagulant (450 ml coagulant/454 kg whey), incubated for 16 hr, and then repasteurized (63°C/30 min) to inactivate the coagulant before ultrafiltration.

Despite high inoculation rates and long incubation periods, the coagulant-treated wheys exhibited little or no differences in flux. This suggested that differences between coagulants, if they existed, originated from enzyme action on milk components rather than on whey components. Therefore, this experimental approach was abandoned in favor of using coagulant produced wheys.

Initially, calf rennet wheys exhibited large differences in permeation flux and recovery of whey protein nitrogen between replicate trials. The differences were so large that they masked the effects of different milk coagulants. However, these variations were reduced by using highly standardized conditions of cheese manufacture and whey processing treatments.

The pH of the wheys at draining ranged between 6.14 and 6.29 with the majority at approximately 6.20. No pH changes greater than .03 pH units were observed between the time of draining and the start of ultrafiltration. Separated wheys consistently contained .05 ± .01% fat by weight.

Pasteurized, separated wheys and their fourfold concentrates (diluted 1:4) were subjected to polyacrylamide gel electrophoresis (9) along with unpasteurized whey and β-lactoglobulin reference.

No differences in band intensities or migration distances were observed upon visual inspection of the stained gels.

Permeate Fluxes and Residual Enzyme Activities

A portion of the permeate flux data is presented in Figure 1. This bar graph shows permeate fluxes 10 min after startup before any degree of concentration was achieved. Each bar is the average of three trials representing one coagulant.

Initial permeate fluxes ranged between 80 and 85 $l/M^2/hr$. The overlapping 95% confidence intervals (the intervals within which 95% of the values would be expected to fall) indicate that the fluxes were essentially the same for

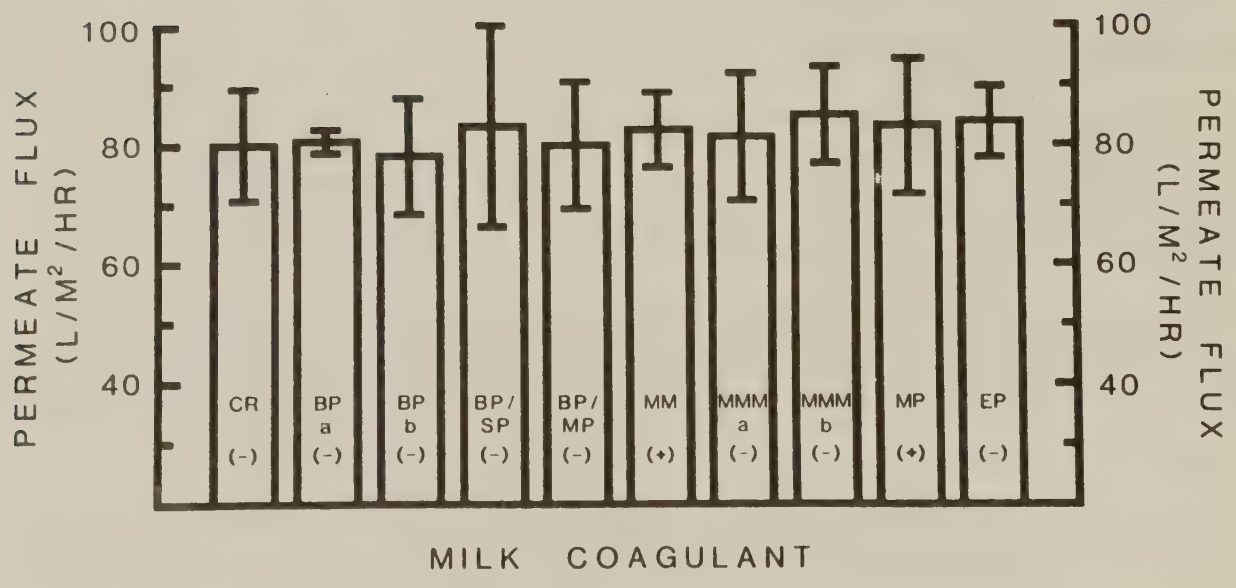

Figure 1. Permeate flux of Cheddar cheese wheys at 0% weight reduction.
(+) residual enzyme activity after heating 63°/30 min.
(-) no residual enzyme activity after heating 63°/30 min.

Coagulants

CR	calf rennet
BP_a	bovine pepsin, commercial sample 1
BP_b	bovine pepsin, commercial sample 2
BP/SP	63:35 bovine pepsin, swine pepsin
PB/MP	bovine pepsin, Mucor pusillus protease
MM	Mucor miehei protease
MMM_a	modified Mucor miehei protease, commercial sample 1
MMM_b	modified Mucor miehei, commercial sample 2
MP	Mucor pusillus protease
EP	Endothia parasitica protease

all coagulants. Analysis of variance showed the same result. No significant differences were observed.

In parentheses near the bottom of the bars are shown a series of pluses and minuses. A plus sign indicates that residual enzyme activity was observed in both the whey and whey protein concentrate whereas a minus sign indicates no residual activity in either.

Residual activity in wheys and whey protein concentrates resulted from only two coagulants. These were the unmodified proteases of Mucor miehei and Mucor pusillus. None of the other eight coagulants including the two modified proteases of Mucor miehei contributed residual activity. Residual activity was never detected in the whey protein concentrates unless it was also detected in the whey.

No attempts were made to quantify the amounts of enzyme activity present. However, Holmes et al. (8) have indicated that the test will detect activity as low as 10^{-4} rennin units/ml. Therefore, those wheys and concentrates that contained activity obviously contained activity equal to or greater than this. Those that showed no activity either contained no activity at all or contained activity below this detection limit.

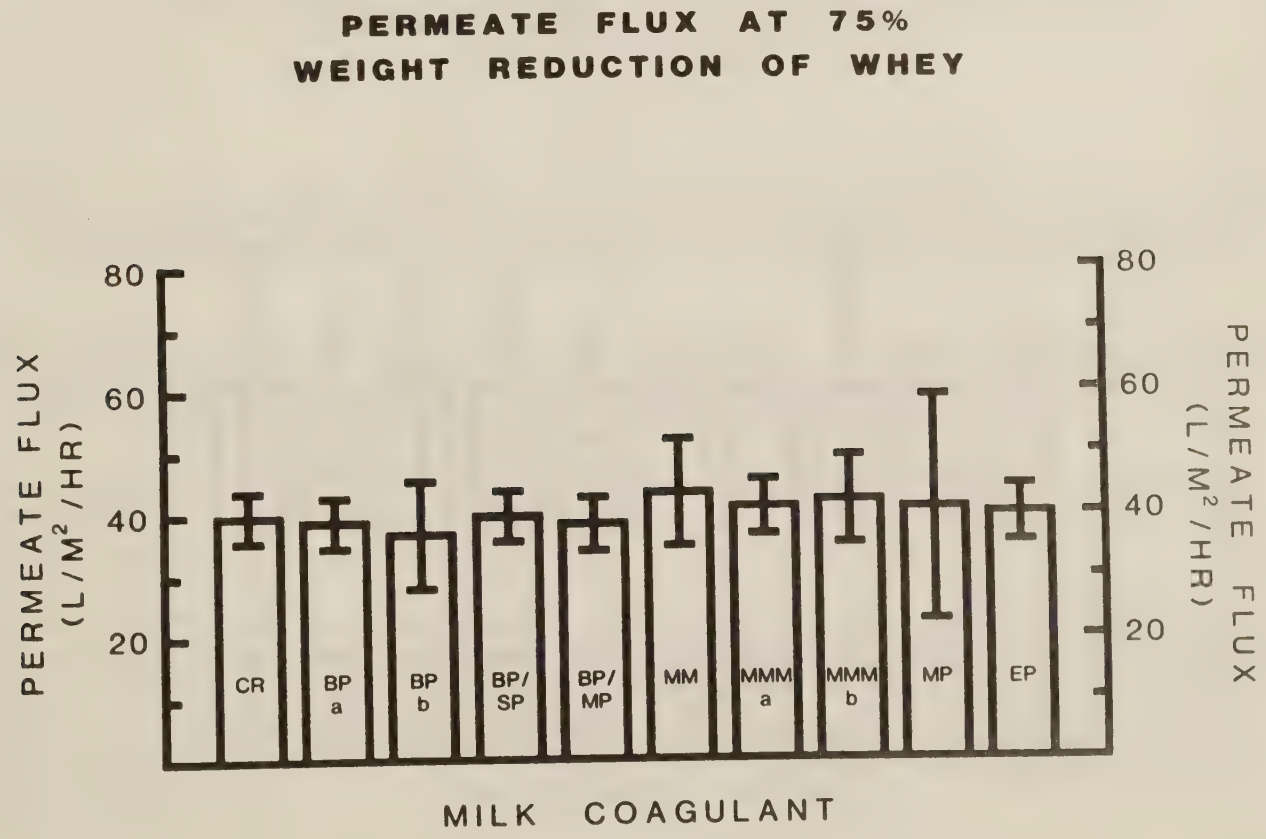

Figure 2. Permeate flux of Cheddar cheese wheys at 75% weight reduction.

Additional permeate flux data are presented in Figure 2. This bar graph shows permeate fluxes after the same wheys had been concentrated fourfold by ultra-filtration (75% weight reduction). Again, each bar represents the average of three trials representing one coagulant.

At this level of concentration, permeate fluxes ranged between 35 and 45 $1/M^2/hr$. It may be tempting to conclude that fluxes were low when bovine pepsin was used as a milk coagulant and sightly higher when Mucor miehei protease was the coagulant. However, an examination of the 95% confidence intervals reveal that the differences were not significant.

Nitrogen and Protein Yields

Total nitrogen yields in the whey protein concentrates are presented in Figure 3. Each bar represents the average of three replicate trials with a single enzyme. Overall, total nitrogen recoveries were about 89% and the yields were essentially the same for each coagulant.

Figure 4 shows nonprotein nitrogen yields in the whey protein concentrate which were between 35-40% and showed slightly more variation among coagulants

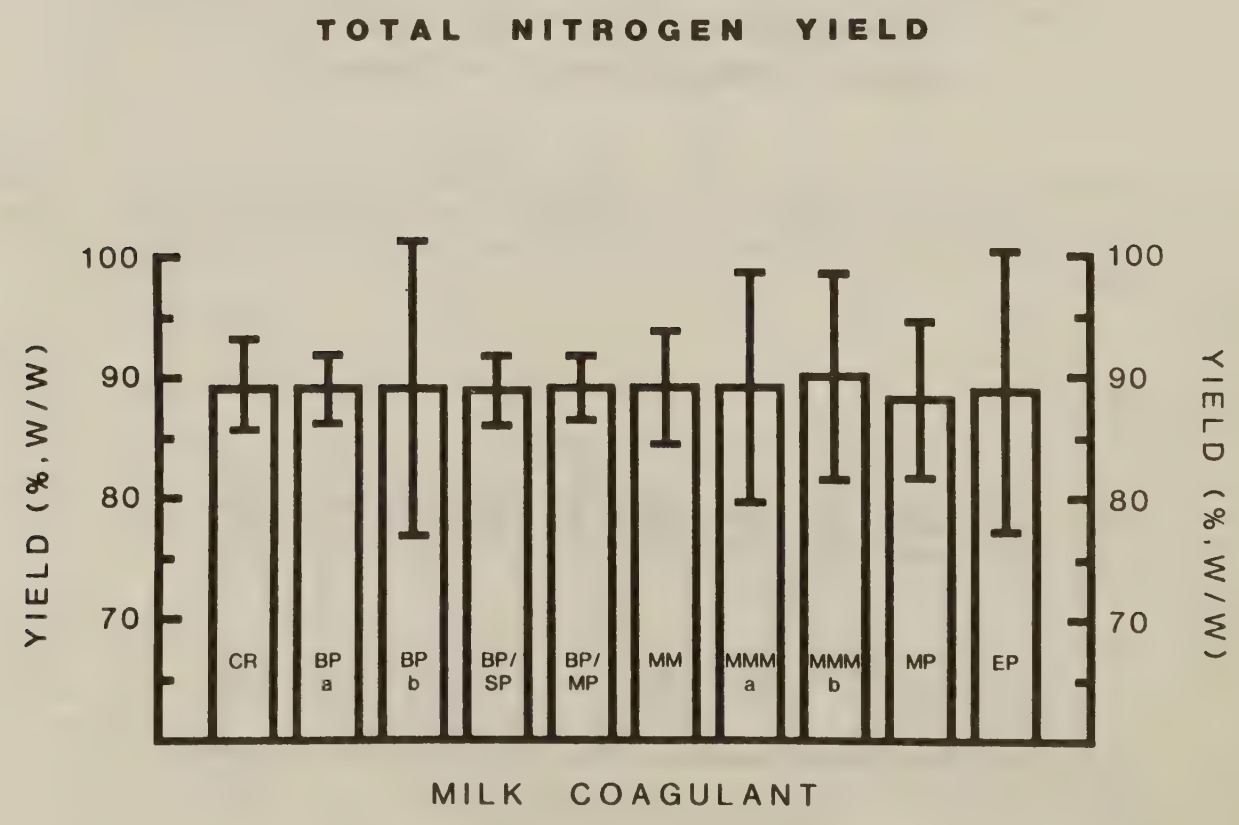

Figure 3. Total nitrogen yields in whey protein concentrates made from Cheddar cheese wheys concentrated fourfold by ultrafiltration.

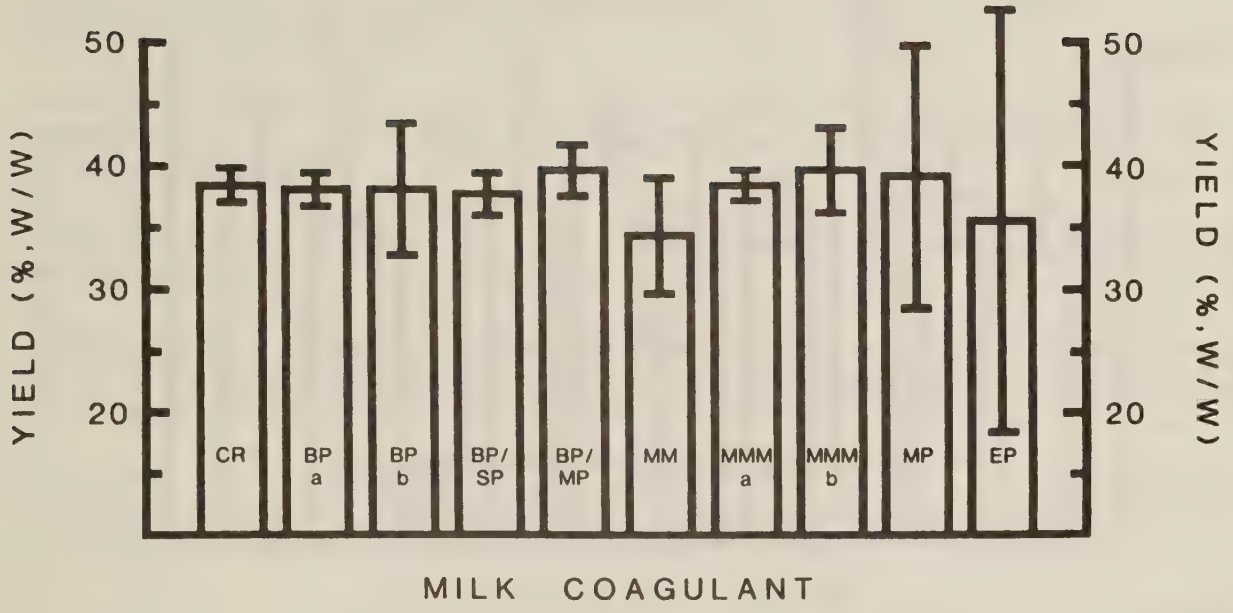

Figure 4. Nonprotein nitrogen yields in whey protein concentrates made from Cheddar cheese wheys concentrated fourfold by ultrafiltration.

than total nitrogen yields. However, an analysis of variance showed that even these differences were statistically insignificant (see overlapping 95% confidence intervals in Figure 4).

True protein recoveries in the concentrate are shown in Figure 5. Each bar is the average of three replicate trials representing a single enzyme. No significant differences were observed.

The protein yields were consistently greater than 100%. These yields in excess of 100% resulted from overconcentration due to permeate losses through the side of a plate and frame ultrafiltration unit. However, these losses were not considered to be a problem in this study as frequent checks showed that the permeate losses were approximately equal for each ultrafiltration trial.

CONCLUSIONS

This study has confirmed the work of others (8) that the unmodified proteases from Mucor miehei and Mucor pusillus are relatively heat resistant and are not

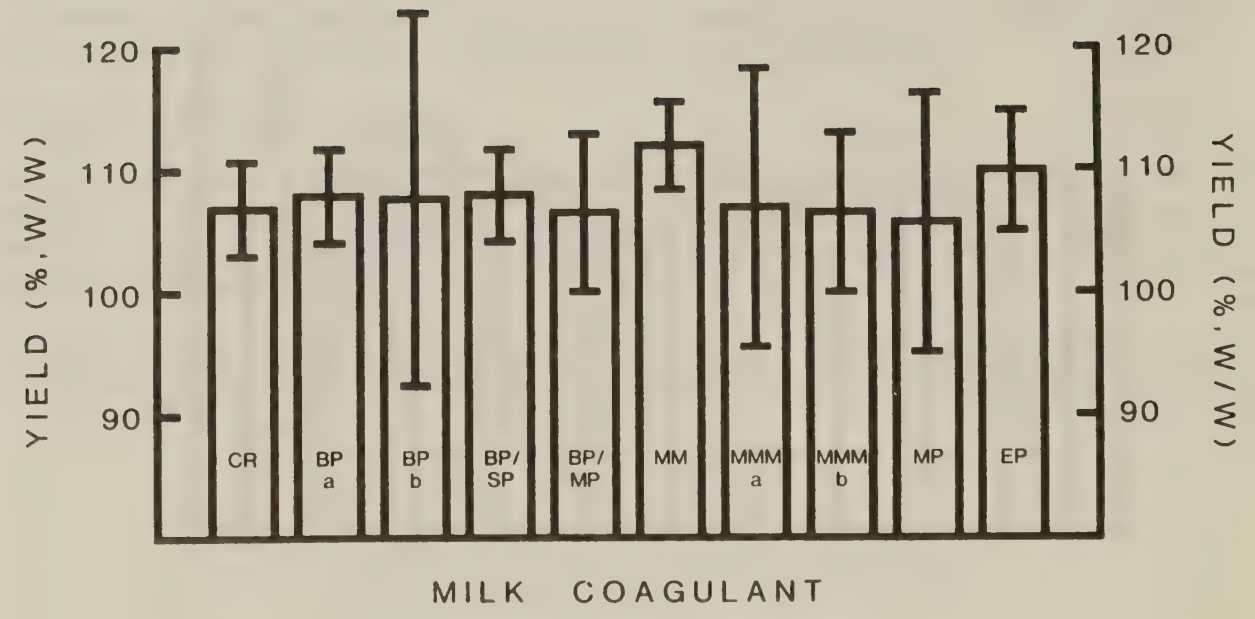

Figure 5. True protein yields in whey protein concentrates made from Cheddar cheese wheys concentrated fourfold by ultrafiltration.

inactivated by pasteurization (63°C/30 min). However, the modified proteases of Mucor miehei were less heat resistant and were inactivated by pasteurization.

None of the milk coagulants have a significant effect on permeate flux or nitrogen recovery in whey protein concentrate provided the conditions of cheesemaking and whey treatment are rigidly controlled. Other factors such as pH, temperature, and whey pretreatments appear to have a much greater effect on flux and yield than do the milk coagulants.

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DEVELOPMENT OF A WHEY-CHITIN SYSTEM FOR ANIMAL NUTRITION

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The shellfish and food processing industries are being confronted increasingly with problems of proper disposal of their byproducts and the profitable return of such materials into the food chain and other markets. In the recent past, some progress has been made in utilizing byproducts of the shellfish and cheese industries. However, due to strong demand for shellfish (crab, shrimp, lobster) and cheese, the increase in production is generating increased wastes from these industries. Consequently, the majority of the more than 100 million kg of the annual United States production of shellfish processing waste is disposed of into the municipal sewage system, streams, landfill disposal sites, and coastal zone areas (1, 2). In addition to the serious environmental pollution problems, this practice represents an economic loss to the industry.

Chitin, poly-β-(1→4)-N-acetyl-D-glucosamine, is a cellulose-like biopolymer and a major constituent of shellfish processing waste. Chitin has an unusual combination of properties including toughness, bioactivity, and biodegradability. Recent research and development has uncovered new uses for chitin and its derivative chitosan (deacetylated chitin) in medical sutures, films and fibers (3, 4), water purification (5), chromatography (6), as animal feed supplement (7-9), wound healing (10, 11), delivery and controlled release of pharmaceutical preparations (12, 13), and as an aid for increasing crop yield (14). However, additional continuous research and development are necessary to establish further utilization and appropriate markets for high-value recovered products and for the waste material.

Production and utilization of cheese whey has been the subject of much discussion for many years, especially what to do with the surplus whey. In 1981 (1), nearly 10 billion kg of whey were produced in the United States as a byproduct of cheese manufacturing. Approximately 50% of production is being utilized in a number of markets while the remainder is normally released into the environment (15). In addition to the economic and nutrient losses, the dumping of whey is considered the strongest environmental pollutant of any kind (16, 17). Furthermore, the pollution associated with the disposal of whey worsens each year as the demand for cheese continues to grow (18).

Whey is rich in nutrients, for it retains about 55% of the nutrients present in whole milk. Among other things, dried whey contains nearly 13% protein of high biological value and about 70% lactose. This high quantity of lactose in dried whey is the reason for its underutilization as a food source since the prevalence of lactose malabsorption and intolerance ranges from 70-90% in some populations in Africa, Asia, Latin America, and the United States (19-23). A similar incidence of intolerance exists in most adult animal species. Progress in this area, therefore, will depend on increasing the ability of an individual (animal or human) to digest larger quantities of lactose in the diet.

Unlike in most microorganisms, lactase is not an inducible enzyme in humans and most animals. For this reason, we undertook to stimulate the growth of certain beneficial lactase-containing bacteria in the gut, thereby supplying lactase to the individual indirectly (7, 8). This approach is based on the discoveries (24, 25), neglected for some 30 years, that alkyl N-acetyl-D-glucosamine (GlcNAc) glycosides promote the growth of Bifidobacterium bifidus var. pennsylvanicus (Lactobacillus bifidus var. pennsylvanicus by the early terminology). Gyorgy and his associates showed that B. bifidus var. pennsylvanicus thrived in the intestine and feces of breast-fed infants while these were limited or absent from the intestine and feces of infants fed cow's milk (26, 27). These bacteria synthesize their own lactase (28) and thus help in the digestion of lactose in whey. It was demonstrated that this strain of bifidobacteria requires for growth specific factors found in human milk and that these factors are virtually absent from cow's milk (26, 27, 29, 30). Therefore, some infants who are fed cow's milk may have problems with indigestion, colic, and susceptibility to infection. Human milk growth factors are either entirely carbohydrates (such as GlcNAc or oligosaccharides) or glycoproteins (24, 31, 32, 33, 34). The growth promoters serve as a source of glycosidically-bonded GlcNAc residues for bacterial cell wall biosynthesis. It should be noted that the GlcNAc moiety (Figure 1) is the monomer of chitin and a constituent of several important biopolymers including heparin, the hyaluronic acid of vitreous humor, synovial fluid, and as mentioned earlier, human milk and colostrum.

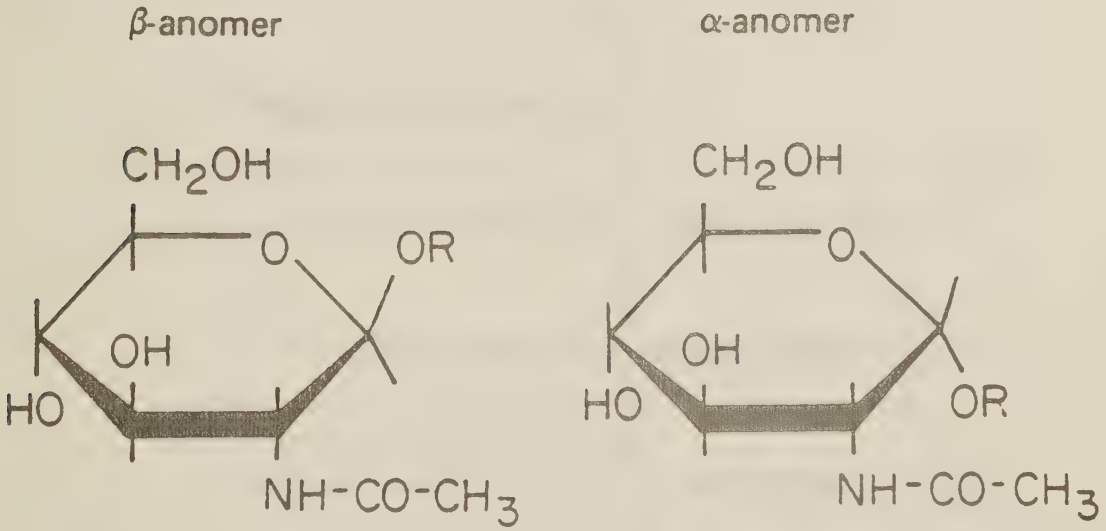

Figure 1. Alkyl N-acetyl glucosamine (GlcNAc) glycosides. The β anomer is bioactive while the α form is inactive. (Ring hydrogens omitted for clarity.)

My interest is in the bioconversion of wastes from the cheese manufacturing and shellfish processing industries to increase the food supply, to help meet food shortages projected for the latter part of this century (35), and to

alleviate a growing waste disposal problem (1, 18). Although in the past crab meal and whey have been used individually in animal feeds (36-39) with some success, to my knowledge no nutritional studies have been performed utilizing both byproducts in the same diet, except our own studies (7, 8, 9, 40, 41, 42). The high content of calcium salts (up to 40%) in crab meal and the large quantity of lactose (over 70%) in whey have been limiting their bulk use in animal feeds. The successful utilization of surplus whey and shellfish processing wastes would help increase the food supply, reduce the cost of food production, reduce environmental pollution, and provide economic incentives to the cheese and seafood industries.

Monogastric Nutritional Studies

Initially we tested our working hypothesis (Figure 2) in rats using 1-propyl-GlcNAc glycoside as chitinous supplement to high whey-containing diets. After 8 weeks, rats on a diet containing 30% dried whey and 1.2% 1-propyl-GlcNAc glycoside, gained more body weight than rats on the same diet without 1-propyl-GlcNAc (9). The latter group of rats showed lack of appetite, developed severe diarrhea, cataract, and eventually died from dehydration and malnutrition. Although these findings are significant, the high cost of the chitinous supplement (presently unavailable commercially) would prohibit any large-scale application of this technology.

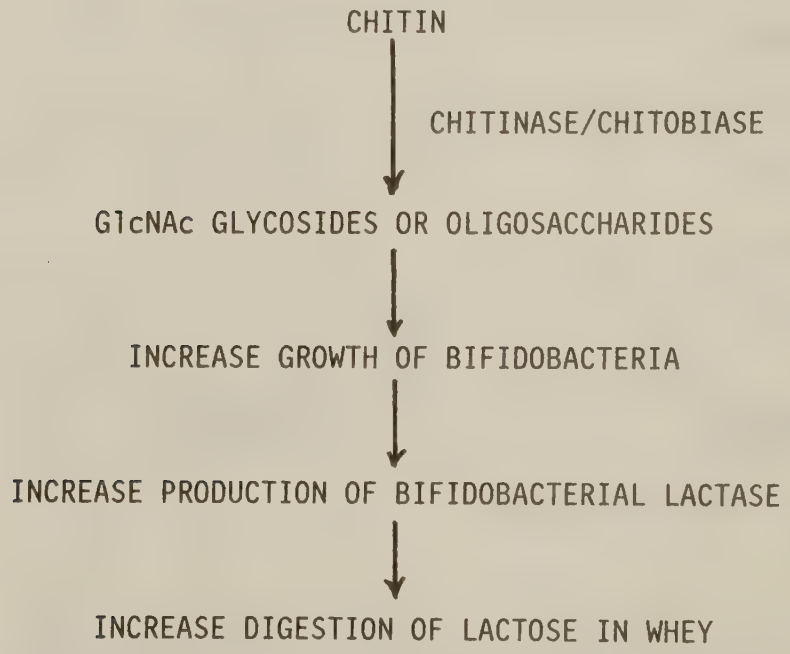

Figure 2. Flow diagram of the working hypothesis.

In order to reduce the cost of the chitinous supplement, we had to find an animal model whose gastrointestinal tract contained chitinolytic activity.

This would permit feeding less expensive chitinous materials. We found that the chicken is a good model for testing our hypothesis because its gastrointestinal tract contains chitinolytic activity (43), it is the least efficient metabolizer of whey (36, 44), and the poultry industry would be the major user of whey.

Using broiler chickens, we conducted three feeding experiments using microcrystalline chitin (MCC), double-sheared chitin (DSC), and commercially available ground chitin. MCC was prepared in our laboratory (9) at a cost of about $1,000.00/kg; DSC was prepared from commercial chitin (which was purchased at $7.00/kg) by reducing its molecular weight. The molecular weight of chitin was reduced from about 2,300,000 to between 350,000-450,000 by first reducing its particle size in a high-speed Waring blender and then grinding it in a Wiley mill to pass a 60-mesh sieve.

TABLE I. Composition of diets used in experiment 1

Ingredients	Diet 1	2	3	4
	. . . . . %			
Commercial lactose-free diet[a]	100	94.5	63.5	57.5
Dried sweet whey (68% lactose)	0	0	20.0	20.0
Microcrystalline chitin	0	2.0	0	2.0
Soybean meal	0	2.5	12.0	15.0
Corn oil	0	1.0	4.5	5.5

[a] Southern State Cooperative, Inc. starting and growing mash with coccidiostat.

The first experiment tested MCC. Each of the four diets (shown in Table I) was fed to a group of 5 male and 5 female 4-day-old Ross X Arbor Acre broiler chicks which were debeaked, vaccinated, and assigned randomly to wire cages. All diets were formulated isonitrogenous (23.5% protein), isocaloric (3,160 kcal/kg metabolizable energy), and fortified with equal amounts of vitamin and trace mineral supplements. The results of the 46-day experiment showed that chicks fed 2% MCC and 20% whey were significantly heavier ($P < 0.05$) than the controls (see Figure 2) (9). Chickens in groups 2 and 3 gained less weight than those in group 1, suggesting that when either MCC or whey was added to the diet alone, weight gain was depressed. This effect was overcome when both MCC and whey were added to the diet of group 4. Birds on

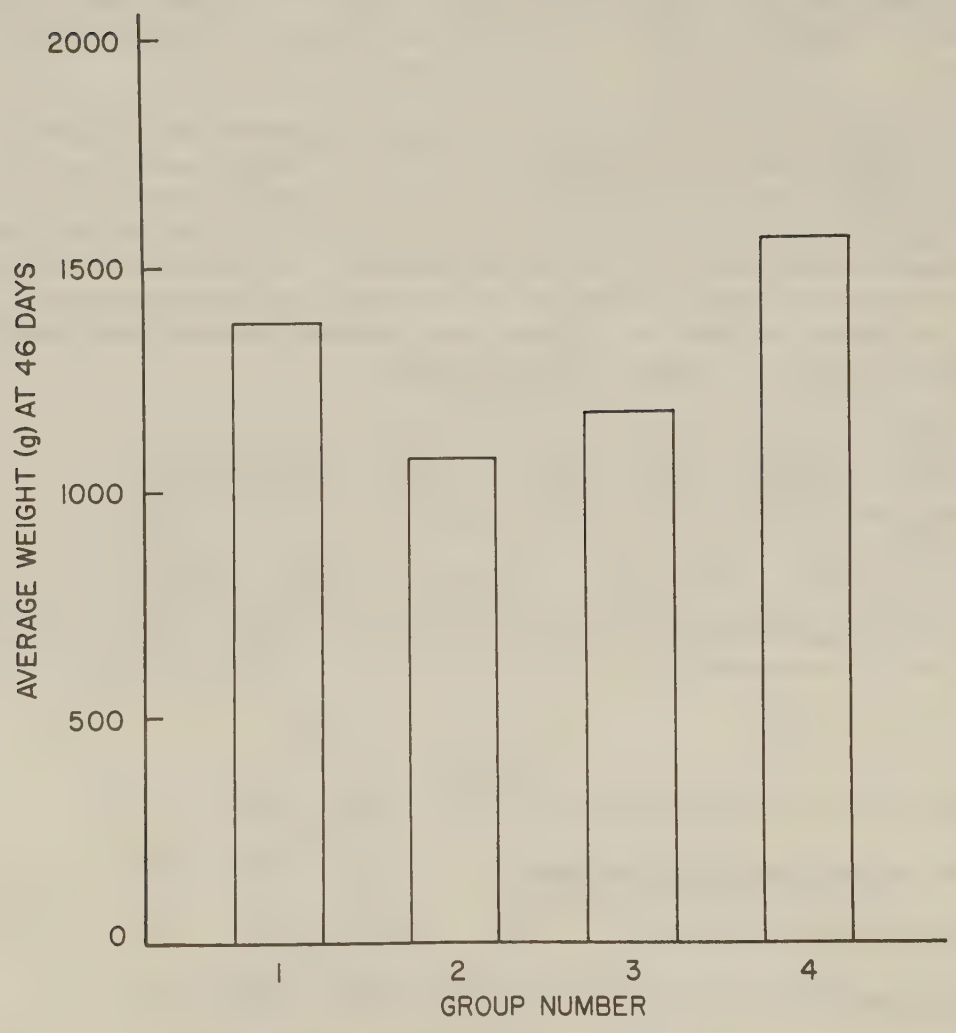

Figure 3. Comparison of chicken mean final weights at 46 days of age. Chickens fed diet 4 were significantly heavier ($P < 0.05$) than those fed diet 2 or 3.

whey without MCC developed severe diarrhea, their feathers were drier, and had more broken body feathers. Birds on the test diet (group 4) were initially diarrhetic but gradually became virtually normal.

The second chicken experiment is a repeat of the first experiment conducted under similar conditions, except for substituting 2% DSC for 2% MCC as the chitinous supplement in diets 2 and 4 and that chicks were 1 day old. Statistical analysis of the data (Table II) from this experiment showed that birds fed the DSC-whey diet weighed significantly more ($P < 0.01$) than birds fed diets 1, 2, or 3 (7). These results demonstrated that growth retardation from dietary whey was overcome by the addition of DSC to the diet. The

chitinous supplement controlled diarrhea as described under the first experiment. Neither whey nor DSC had any adverse effect on the appetite of the birds. Necropsies at the end of the 31-day experiment revealed that all birds from the group fed whey without DSC showed severe intestinal hemorrhage, enlarged intestine, and enlarged ceca. The gizzards of birds receiving whey and DSC peeled easier (a desirable characteristic) than those raised on the commercial diet. The abdominal fat pads of birds fed whey and DSC were smaller than those on the commercial diet. This interesting observation led us to weigh this tissue in the third experiment.

The third experiment involved a larger number of chickens and was designed to test the effectiveness of commercial chitin (without reduction in molecular weight) as the chitinous supplement to whey in a randomized block design of floor pens. Notice that in order to simulate commercial conditions, the chicks were raised in floor pens rather than in wire cages as was done in previous experiments. Each of the four diets was fed to three replicate pens (numbered 1 to 12): Diet 1 (100% commercial ration, control) included replicates 1-3; diet 2 (2% chitin, control), 4-6; diet 3 (20% whey, control), 7-9; and diet 4 (20% whey and 2% chitin, test diet), 10-12 each containing 35 male 1-day-old Ross X Arbor Acre broilers. All diets were formulated isonitrogenous (23.5% protein), isocaloric (3,160 kcal/kg metabolizable energy), and were fortified with equal amounts of vitamin and trace mineral supplements. The commercial chitin was ground to 60 mesh and had a molecular weight of 2,300,000. The dried whey was acid whey and contained 73% lactose.

TABLE II. The effect of double-sheared chitin and whey on the mean ± SD weight of broilers from the first experiment

	Days				
Diet	0	7	14	21	31
	grams				
1	81	190	347	546	988[b] ± 29.2
2	87	182	348	518	956[b] ± 26.1
3	86	180	298	480	906[a] ± 25.9
4	80	194	359	609	1105[c] ± 31.6

[a,b,c] Means ± SD with different superscripts are significantly different ($P < 0.01$).

The growth trends were similar to those observed in the second experiment. Analysis of variance indicated a highly significant diet effect ($P < 0.0005$). Statistical analysis showed no significant weight gain differences among diets 1, 2, and 4 (Table III). However, chickens fed diet 3 (standard diet + 20% whey) weighed significantly less ($P < 0.01$) than those fed diets 1, 2, or 4. Furthermore, birds raised on diet 3 had significantly poorer ($P < 0.01$) feed efficiency than those fed diets 1, 2, or 4 (7). In addition to the poor growth, birds in this diet suffered from severe diarrhea. At the end of the trial, 70 chickens (10 birds each from replicates 1, 3, 4, 5, 7, 11, and 12) were picked randomly, the abdominal fat pads removed, and the fat weights recorded. Ratios of individual body weight to fat pad weight were determined. Statistical analysis of mean ratios of body weight to fat in the abdominal fat pads demonstrated that differences were not significant in replicates 11 vs. 12 (from diet 4), 1 vs. 3, 4 vs. 5, and 5 vs. 7. However, the differences were highly significant ($P < 0.01$) when comparing replicates 11 and 12 vs. 1, 3, 4, 5, and 7 (7). These results confirmed our previous observations with MCC and DSC experiments and establish that chickens gained the least body weight in diets containing 20% whey without chitinous supplement. Furthermore, such whey-chitinous diets produced chickens with significantly less abdominal fat without reduction in body weight than chickens raised on a commercial broiler ration.

TABLE III. The effect of ground chitin and whey on the mean ± SD weight and feed efficiency of chicks from the third experiment

	Days				
Diet	0	9	24	44	Feed Efficiency[a]
	grams				
1	77	221	803	1739[b] ± 72.3	1.83[b] ± 0.04
2	75	229	823	1745[b] ± 67.1	1.86[b] ± 0.09
3	78	214	788	1669[b] ± 70.1	2.10[c] ± 0.10
4	78	246	831	1782[c] ± 78.6	1.81[b] ± 0.02

[a] Calculated at 44 days of growth.

[b,c] Means ± SD with different superscripts are significantly different ($P < 0.01$).

In our studies, we have assumed that the improved utilization of whey in the chicken is attributed to the change in the intestinal microflora brought about by the chitinous supplement. In a recently completed study (41), we attempted to find out whether diet manipulation can modify the bacterial population in the chicken gut. Two replicate nutritional experiments were performed, each of which contained 11 groups of 1-day-old broiler chicks. The various isonitrogenous/isocaloric diet treatments received ethyl-GlcNAc glycoside, chitin, and/or Bifidobacteria inoculum, and whey. After feeding for a minimum of 10 days, 3 out of 5 birds per group were sacrificed, intestinal samples collected, cultured on a selected medium, and isolated cultures biochemically characterized. In both experiments on the basis of morphological and biochemical results, we found that 4 out of 11 groups of birds contained Bifidobacteria in their intestine. These were chicks in the group 2 receiving ethyl-GlcNAc glycoside, group 6 on ethyl-GlcNAc glycoside and bacterial inoculum, group 8 on chitin, and group 11 on chitin, whey and

TABLE IV. Change in crab meal composition due to demineralization

Component (%)	Raw crab meal	DCM[a]	Percent change
Crude protein	34.75	62.64	80.3
Gross energy[b]	2.48	4.84	95.1
Moisture	9.90	5.55	-43.9
Ash	40.66	6.73	-83.5
Calcium	16.90	.67	-96.0
Acid detergent fiber	11.6	29.7	156.0
Chitin	14.6	34.2	134.3
Ether extract	1.42	3.36	136.6
Quantity	453.6[c]	140.6[d]	-69.0

[a] Demineralized crab meal.

[b] Mcal/kg.

[c] kg dry commercial meal processed.

[d] kg dry DCM resulting from demineralization.

bacterial inoculum. Although these findings are supportive of the influence of chitinous supplement on the microflora, results from four other dietary groups containing chitinous supplement were not as conclusive. Furthermore, as a consequence of this study, we developed a reliable selective medium for the sustained culturing of a control population of Bifidobacterium bifidus var. pennsylvanicus (41).

Demineralization of Crab Meal

In order to reduce further the cost of chitinous supplement, we developed an inexpensive large-scale demineralization method (8). Very briefly, demineralization was carried out in a 2,000-l fiberglass reactor tank using 1 N nitric acid. The crab meal-acid slurry was stirred continuously for 2 hr and then its pH adjusted to about 4 with the addition of aqueous sodium carbonate. This step was necessary to discharge the liquid material into the sewage system. The demineralized meal was collected from the drainpipe of the tank, washed until it reached pH 6, and dried in a large drying oven. Analyses showed (Table IV) that the demineralized procedure removed nearly 90% of the calcium and 86% of the ash. In addition, it doubled the content of protein (67%), fiber (23%, which is mostly chitin), and energy (4.9 kcal/g), and tripled the amount of fat. This product is an excellent source of protein and chitin for animal feed and can replace soybean.

Ruminant Nutritional Studies

Since the data from these studies has been submitted for publication elsewhere (8), only a summary of the methods and results will be presented here.

Two feeding experiments were performed to evaluate the use of crab meal, either demineralized or raw, as a supplemental aid for the digestion of whey-rich rations. Each experiment utilized 16 young ruminating Holstein heifers (about 4 months old) in a 4 X 4 Latin square design, blocking on weight and pen. Rations were isonitrogenous and isocaloric formulated to meet Nutritional Research Council nutrient requirements. Rations for experiment I were as follows: Ration 1 (positive control) contained corn, soybean meal, and hay; Ration 2 (whey control) substituted 25% dried sweet whey for a percentage of the grain in Ration 1; Ration 3 (crab meal control) substituted 12.5% demineralized crab meal for a percentage of the grain of Ration 1; Ration 4 (experimental ration) substituted 25% dried sweet whey and 12.5% demineralized crab meal for a portion of the corn and all the soybean meal of Ration 1. Rations for experiment II were similar to those for experiment I, except 30% whey replaced the 25% level and 15% raw crab meal replaced the 12.5% demineralized crab meal. The duration of experiments I and II were 33 and 31 days, respectively.

Statistical analysis of the data showed no significant dietary effect on net weight gain or feed efficiency for either experiment. Diarrhea increased significantly by including whey in Ration 2 of both experiments. However, the addition of crab meal to whey-containing rations returned the feces to normal. In both experiments, whey depressed the nutrient digestibility of the ration. While raw crab meal also depressed ration digestibility (experiment II, crab meal control Ration 3), demineralized crab meal resulted in

nutrient digestibilities equal to those measured for Ration 1 (experiment I, crab meal control Ration 3). The addition of either crab meal to the experimental rations of both experiments (Ration 4) resulted in ration nutrient digestibilities similar to those afforded by the grain/hay, Ration 1.

This research indicates that crab meal (either raw or demineralized) when added to the diet, increases the digestibility of rations containing high quantities of dried whey. Furthermore, the induced diarrhea associated with the ingestion of whey is overcome when whey containing rations are supplemented with either type of crab meal. In fact, the results point out that it may be possible to even increase further the amount of whey in calf ration, perhaps 40-60%, and crab meal to 20% without adverse affect on growth.

Chitinase From Soybean Seeds

One of our goals in this research is to increase the digestive capacity of humans (and other monogastrics without intestinal chitinolytic activity) to lactose-rich diets. If successful, whey and other lactose-rich foods would be readily utilizable by people and at the same time provide relief to millions of lactose intolerants. Theoretically, this can be achieved either by including in the diet GlcNAc glycosides or chitin plus chitinase. Due to the high cost of GlcNAc glycosides, the first possibility is economically unfeasible. The second possibility would be practical if an inexpensive and plentiful source of chitinase can be found.

In the pursuit of the second possibility, we discovered that soybean seeds are rich in chitinase. Using a specially prepared affinity column (with chitin as ligand), we developed a method for the purification of chitinase from soybean seeds for the first time (6). We achieved a purification of about 258-fold and identified five protein peaks, three of which also contained chitobiase activity. The average molecular weight of chitinase was 31,600 daltons as determined by SDS-polyacrylamide gel electrophoresis. Preliminary results indicated the enzyme acts as an endochitinase and a number of isoenzymes may be present. The enzyme exhibited a relatively low pH optimum in the range of 3.3-4.0 and appeared to be inhibited by potassium ion. The procedure is simple, inexpensive, and yielded chitinase of higher purity and specific activity than two out of three commercial enzymes assayed. Because soybean is inexpensive and readily available, if this method is used commercially it would produce high-purity chitinase at a fraction of the cost required by present commercial methods extracting the enzyme from microorganisms. Furthermore, this purification method allows the use of the remaining soybean material (more than 99% of the proteins, oil, etc., in soybean seeds) once the enzyme is isolated.

In view of the above, an easier and less costly alternative to providing chitinolytic activity to the human gut would be the supplementation of lactose-rich foods with a combination of chitin and soybean flour. This approach would be worth studying first with monogastric animals lacking chitinolytic action in the gut and then with human volunteers.

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THE USE OF IMPEDANCE MONITORING TO RAPIDLY DETERMINE THE MICROBIOLOGICAL QUALITY OF DAIRY PRODUCTS

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INTRODUCTION

Standard Methods for the Microbiological Analysis of Dairy Products require the serial dilution of samples in a suitable fluid followed by the preparation of multiple pour plates (March, 1978). Such procedures are labor-intensive, necessitate the preparation and tempering of molten agar, and require extended incubation periods ranging from 48 hr for the total plate count to 10 days for determining the level of psychrotropic contamination. Other routine dairy procedures such as the detection of yeast and the prediction of product shelf-life are also associated with prolonged incubation periods before results are available.

Thus by relying on Standard Methods the dairy processor must often be satisfied with test results which are of purely historical value. Since these results are often available only after the product has been processed and has in most cases already entered the distribution chain, the potential effectiveness of the laboratory can become compromised. Furthermore, since many dairy products are opaque or in powdered form, plate counts may require interpretation by experienced laboratory personnel.

This review covers impedance methodology and procedures developed by the Research and Development group at Bactomatic, Incorporated. It provides the dairy processor with simplified procedures which can produce test results within a significantly shortened and, therefore, more meaningful time frame. This permits the processor to determine product quality before processing or prior to its introduction into the marketplace. Table I depicts several of the potential benefits of impedance monitoring which are of particular interest to the dairy processor.

TABLE I. Advantages of impedance monitoring to the dairy processor

Minimal sample preparation required
Automated test procedure
Earlier test results when compared to traditional methods
Grossly contaminated product detects earliest
Only viable microorganisms measured
Unaffected by opaque samples/particulate matter

PRINCIPLE OF IMPEDANCE MONITORING

Impedance is defined as the "total resistance to flow of an alternating current through a conductive medium" (generally a microbiological growth medium). The test media employed can be selective or nonselective depending upon the requirements of the specific application under investigation.

The total impedance signal (Z) is composed of two separate components: the Capacitance (C) and Conductance (G) signals. The G signal results from changes in the bulk solution filling the sample container whereas the C signal is associated with ionic changes in close proximity to the electrodes. Total impedance (Z) is a function of these two individual components. As microorganisms metabolize complex substrates in the growth medium (e.g., proteins, carbohydrates, and lipids), they generate end products that are smaller, more completely ionized, and more mobile. Collectively these factors contribute to a net change in the impedance components of the growth medium. When employing impedance technology three alternative signals (C, G, or 1/Z) can be monitored. The signal chosen for a specific application is determined by the medium employed, the product, and the specific populations of microorganisms to be monitored (Firstenberg-Eden and Zindulis, 1984).

THE BACTOMETER® M123 MICROBIAL MONITORING SYSTEM

The Bactometer® M123 Microbial Monitoring System

The Bactometer® M123 Microbial Monitoring System is a fully automated microprocessor-controlled instrument capable of generating a nondestructive electrical current across the sample and measuring resultant charges in the impedance signals associated with microbial metabolism.

Figure 1 depicts the Bactometer® M123 Microbial Monitoring System. The system as shown contains an LSI-11/23 microprocessor, Bactometer® Processing Unit (BPU), video terminal, and high speed printer. A Digital Plotter (not shown) is included for preparing permanent copies of any impedance curves or calibration curves upon demand.

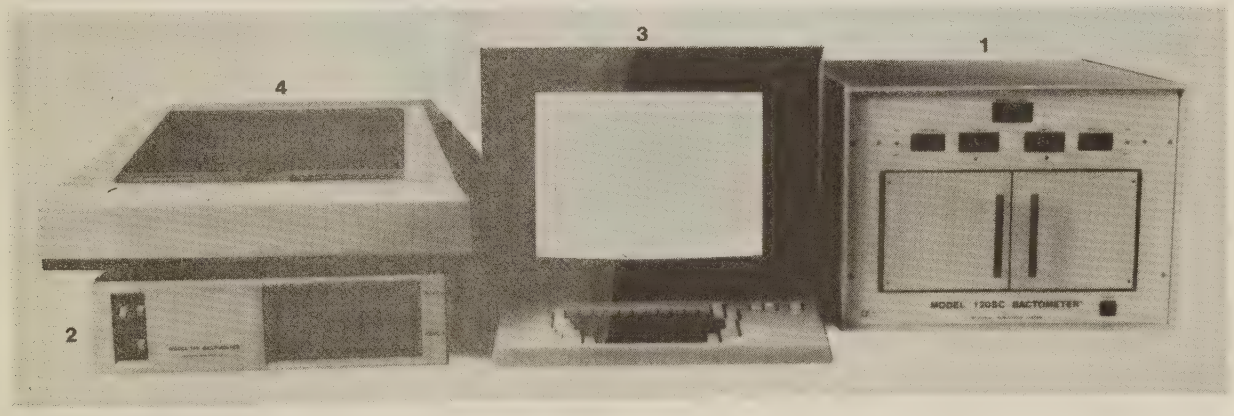

Figure 1. The Bactometer® M123 Microbial Monitoring System consisting of (1) the Bactometer® Processing Unit, (2) LSI-11/23 Microprocessor, (3) Color Video Terminal, and (4) Serial Printer.

The Bactometer® Processing Unit contains two individual incubator chambers capable of monitoring up to 128 samples at two different temperatures. Once the monitoring cycle has begun, the instrument automatically monitors changes in the specific impedance signal selected for the time frame designated by the operator.

During an experimental run, data are continually updated, and impedance detection times for all samples are displayed in color-coded form as soon as they occur on the video screen. Permanent hard copy data suitable for documentation purposes are available upon demand. Up to three additional BPU's can be added to the system enabling the experimenter to monitor impedance changes in up to 512 samples simultaneously.

Figure 2 depicts a sterile plastic module containing a sufficient number of test wells to accommodate 16 individual samples. Each well contains two vertical stainless steel electrodes which are attached to a metal lead frame embedded in the plastic base. When performing raw milk applications (e.g., total count and psychrotropic count), 0.1 ml of undiluted sample is pipetted directly onto the surface of a thin layer of agar which has previously been dispensed into module wells. When preparation of product in liquid medium is required (e.g., detection of yeast in yogurt), 1.5 ml of diluted sample is pipetted directly into test wells. After samples have been loaded, sterile caps are aseptically placed over the wells, and the module is inserted into the instrument's incubator compartment. The Bactometer® is then programmed to monitor samples for a length of time designated by the operator.

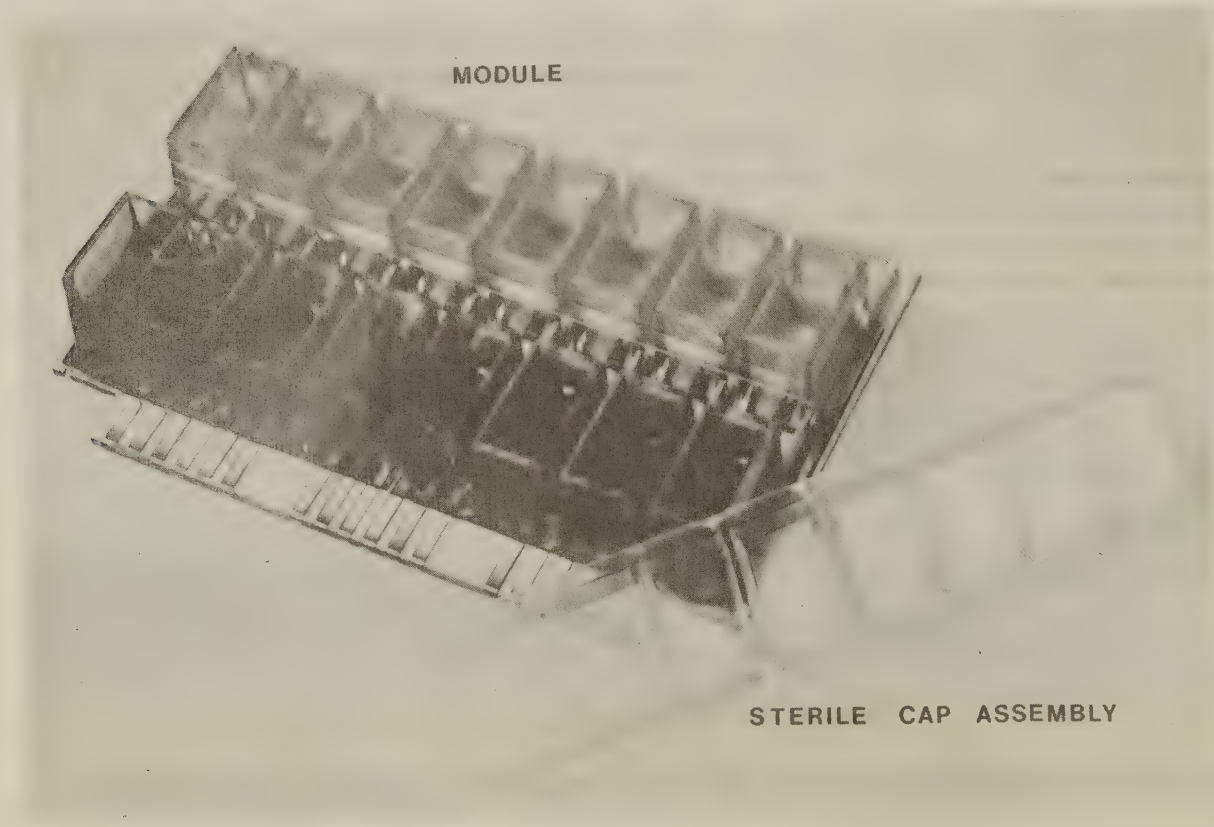

Figure 2. A Bactometer® module and Sterile Cap Assembly.

THE USE OF IMPEDANCE MONITORING IN THE DAIRY INDUSTRY

Impedance assays currently available for evaluating dairy products can be conveniently divided into three general categories: classification of samples into those containing concentration of samples above or below specified limits, sterility testing such as may be required by aseptic juice manufacturers, and the use of impedance data to predict shelf-life.

Calibration Procedures

To establish the relationship between impedance detection times and the results of Standard Dairy Procedures, the user must simultaneously assay a series of samples using the Bactometer® and the reference method. Figure 3 depicts the relationship between impedance detection times for five samples of a single product (raw meat) with different initial microbial concentrations. The most highly contaminated sample containing 5 X 10^7 CFU/g detects within 1 hr while the least contaminated sample containing 8 X 10^3 CFU/g detects approximately 10 hr later.

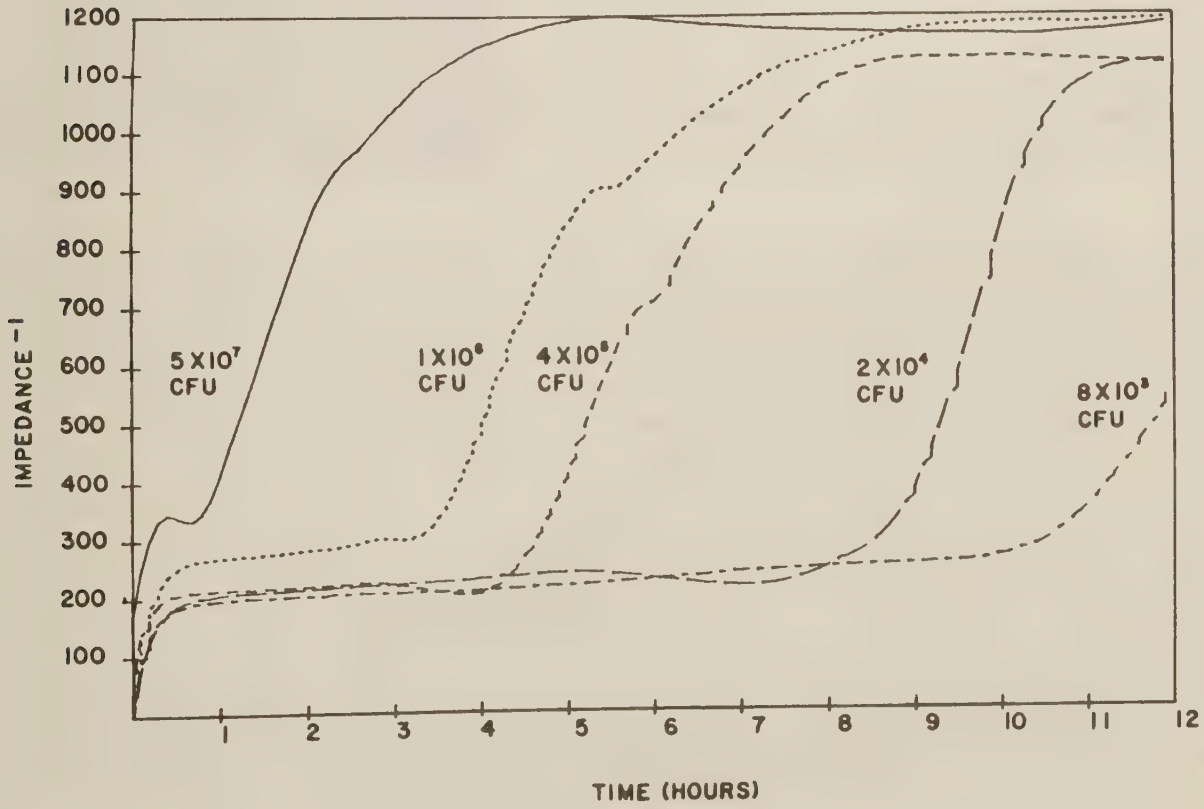

Figure 3. Effect of bacterial contamination level on impedance curves. From Firstenberg-Eden (1983) reproduced with permission from Food Technology.

By entering accumulated impedance and plate count data into the computer, the calibration software can be used to generate a calibration curve, perform regression analysis, and statistically analyze all test data. Test results are automatically plotted on a calibration curve where each point represents a sample's impedance detection time (x axis) and plate count value (y axis).

For statistical purposes samples selected for inclusion in the calibration curve should have bioburdens above and below the specified microbiological limit. By purposely selecting samples with microbial concentrations equally distributed over a 4 to 5 log cycle range, the operator can ensure that the calibration curve will effectively classify future samples as acceptable, unacceptable, and "marginal."

Figure 4 depicts a typical calibration curve prepared from IDT and TPC data for 110 raw milk samples using the calibration software. The instrument automatically calculates product-specific cutoff (15.24 hr) and caution (19.09 hr) times which are used both to color code test results and classify future samples of this product as acceptable, unacceptable, and "marginal."

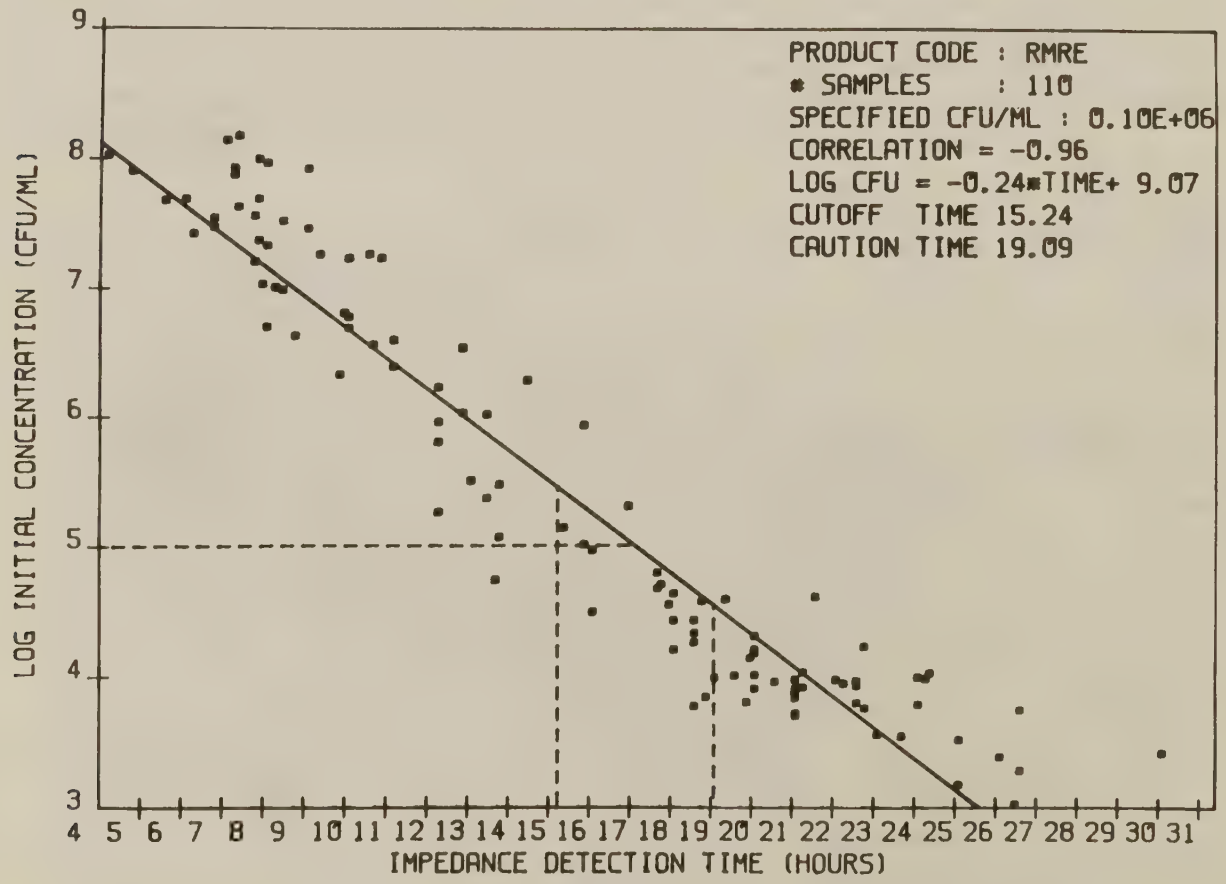

Figure 4. Calibration curve relating impedance detection times to total plate count for raw milk samples. From Firstenberg-Eden and Tricarico (1983) reproduced with permission from the Journal of Food Science.

Specific Dairy Applications

The need for simplified test procedures and more rapid laboratory results stimulated several investigators to evaluate the efficiency of employing an automated impedance assay to screen raw milk samples (Gnan and Luedeke, 1982; Cady et al., 1978; O'Connor, 1979). The less than optimal correlations observed in some of these earlier studies prompted recent investigators to optimize test conditions (i.e., medium and temperature) when assaying this product using the Bactometer® (Firstenberg-Eden and Tricarico, 1983). Based on recently published studies, the inconsistencies previously observed could be attributed to differences in the generation times of the two major groups of contaminating microorganisms (i.e., mesophiles and psychrotrophs) at the original temperatures employed (Firstenberg-Eden and Tricarico, 1983). By lowering the Bactometer® temperature to 18°C, differences in generation times were minimized, and a satisfactory correlation between the impedance method and the standard plate count performed at 32°C was achieved.

Figure 4 depicts a calibration curve prepared for 110 raw milk samples obtained from 14 different dairy farms including samples with wide variations in the ratio of mesophiles to psychrotrophs. The high degree of correlation ($r = -.96$) at the 18°C Bactometer® temperature chosen indicates that under these conditions the impedance assay can be used as an effective alternative to the standard plate count.

Sample preparation for the Bactometer® is less labor intensive than with standard methods, and the calibration curve permits the user to reliably classify future samples into three distinct categories based on their respective IDT's.

Samples detecting prior to 15.24 hr (Red Zone) are unacceptable whereas those detecting after 19.09 hr (Green Zone) are acceptable. Samples detecting between 15.24 and 19.09 hr (Yellow Zone) are classified as "marginal" and contain microbial concentrations in close proximity to specified limits. Furthermore, since all milk samples detecting after 19.09 hr exceed the established cutoff time and therefore occupy the Green Zone, the operator can discontinue the assay at this time.

The mesophilic microflora exceeded the psychrotrophs in most farm fresh raw milk samples evaluated during this study (Firstenberg-Eden and Tricarico, 1983). By increasing the Bactometer® temperature to 35°C it was, therefore, possible to more rapidly detect the presence of the predominant mesophilic population. As shown in Figure 5 when 127 farm fresh raw milk samples were classified using the more rapid "mesophilic screen," all unacceptable and marginal samples were detected within 5.29 hr enabling the dairy processor to obtain meaningful test results within a single working day.

A new Bactometer® protocol has been developed for classifying milk samples according to their level of psychrotrophic contamination (Firstenberg-Eden and Tricarico, 1983). The standard 10 day period required for enumerating psychrotrophs has been shortened to less than 36 hr enabling the milk processor to obtain test results on these more slowly replicating populations within a more practical time frame.

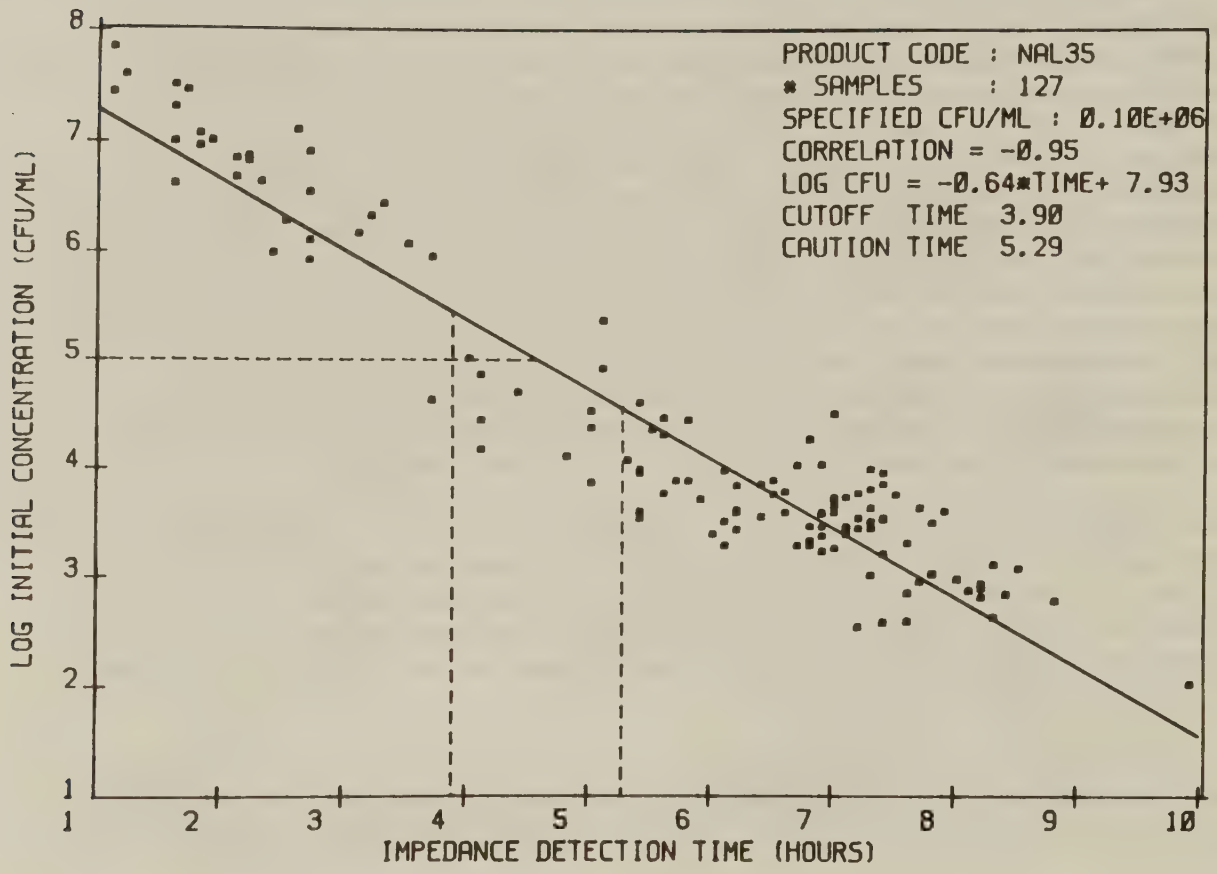

Figure 5. Calibration curve relating impedance detection times to mesophilic plate count for raw milk samples. From Firstenberg-Eden and Tricarico (1983) reproduced with permission from the Journal of Food Science.

By systematically modifying the medium and manipulating the test conditions (i.e., signal, temperature, and test time), impedance technology has been adapted for use with additional procedures of major interest to members of the dairy industry.

The Moseley Test has been intensively studied and has gained wide acceptance as an indicator of the keeping quality of pasteurized milk. Since this procedure requires a preliminary incubation period followed by plating and re-incubation, a time frame of 7 to 9 days is required before test results are completed. A less labor intensive and more rapid Bactometer® assay has been developed which enables the processor to predict shelf-life within 25-38 hr following pasteurization (Bishop, White, and Firstenberg-Eden, 1984). This information can be utilized by milk processors for more effectively planning delivery schedules to distant distribution centers.

Other test protocols and media have been developed for the selective detection of specific groups of microorganisms such as coliforms (Firstenberg-Eden et al., 1984) and yeast (Zindulis, 1984) of particular interest to dairy processing.

CONCLUSIONS

The Bactometer® affords the modern dairy processor an attractive alternative to the traditional procedures currently available for determining the microbiological quality of his products. Impedance procedures are currently available for estimating total and psychrotrophic counts in milk, predicting product shelf-life, as well as the selective detection of specific microorganisms including coliforms and yeast. Impedance procedures are characterized by less preparation time, require smaller volumes of media, and provide the user with earlier and, hence, more meaningful test results.

When employing the Bactometer®, knowledgeable decisions can be made before adding raw materials and prior to shipment of finished product. When properly utilized this information can also reduce the requirement for costly warehouse space, enable the processor to optimize distribution schedules based on projected shelf-life, and prevent costly product recalls.

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THE FUTURE OF WHEY PROTEIN CONCENTRATE //

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For the past 15 years, we have heard from countless experts, numerous prognosticators, and several prophets about the future of whey protein concentrate. Today, at great personal risk, I am joining this select group and will attempt to share with you my opinion of the future of whey protein.

As we look into the future, we need to start from an existing base, and that requires us to take a glance back into the history. While the history certainly doesn't tell us what is going to happen tomorrow, there are many valuable lessons that we can learn from the history to help project the future.

Whey protein concentrate had its commercial birth somewhere around 15 years ago. At that time, whey was a disposal problem of the cheese industry, being amplified by the actions of the EPA. Whey protein concentrate was a technology driven product ... (that means we learned how to make the product before we knew what to do with it). The primary parents of this product were the developers of ultrafiltration, electrodialysis, and jell filtration. Once the basic technology reached puberty (that is, when a teenager knows everything), it began to multiply at a tremendous rate and whey protein concentrate

TABLE I. WPC 34 comparison

	WPC 34	NFDM	Caseinate/Whey 34%
Protein	35%	35%	35%
Lactose	50+	50+	50+
Minerals	6.0	8.0	8.0
Fat	3.5	1.2	1.0
Moisture	4.0	4.0	4.0
PER	3.2	2.8	2.75
Applications	Dairy (Milk Replacer)	Dairy Baking Meats Dry Mixes Etc.	Milk Replacer in Baking Meats Dry Mixes Etc.

became a production driven product (primary motivation was ... we could produce the product). "This technology provided the long-awaited answer to the whey problem in the United States." Those who held the key to this technology sold the technology ... not products. Considerable equipment was sold, and we entered into a new era of whey protein production. There erupted a multiplicity of companies and promoters selling UF plants as the answer to all the problems in the cheese industry.

And quite frankly, they had a very believable story. I would like to refer to my first table showing a comparison between NFDM, WPC, and the then prevalent caseinate whey blend. As anyone can see, the WPC is obviously nutritionally superior to both NFDM and the caseinate whey blend. In addition, its functionality is enhanced because the product is acid soluble. The applications of NFDM and caseinate whey blends were fairly specific, and currently used in quite a few different food products. The WPC was positioned as a milk replacer product.

The promoters of whey protein production systems were preaching that whey protein would sell for a few cents under the price of NFDM; and, in some cases, due to its superior PER, it would sell at a price multiple of NFDM. I can even remember one promoter saying, "Someday they will produce the cheese just to get the whey."

We, the dairy industry, went into production and produced vast quantities of whey protein concentrate. Looking back with 20/20 hindsight, it is obvious now that we produced too much quantity for the market, we had too little quality control (as products were very inconsistent from plant to plant), and we did not have any really effective market development programs. The result is obvious today. We turned a superior speciality product into a commodity selling for a fraction of the price of NFDM.

Today, we produce somewhere between 80 million lbs and 100 million lbs of whey protein concentrate here in the United States. Price of this nutritionally superior product ranges from 50% to 60% of that of NFDM. Estimates are that upwards of 25% of this production is still going into the animal feed area.

However, we have come a long way in the past 10 years, and have made some real progress. Overall, we are producing about 3 billion lbs of whey solids a year, and we further process slightly over half of these solids. About 20% of the whey solids we process are moving into whey protein concentrate today.

Where are we today?

Today, our WPC is produced mostly on ultrafiltration equipment. We have developed a product that is much more consistent, has reasonably uniform quality, and we have learned to control our bacteria levels, the amount of enzyme activity present in the product, and to modify the product to fit specific needs. We are currently in a gradual process transforming from a production driven industry to that of a market driven industry. Market driven fills the needs of our customers, and these customers actually want to buy the product. We are beginning to listen to what our customers'

wants, needs, and desires are. The key to the future is in filling the needs of our customers. I am going to be presumptuous enough to suggest three ways which we can position our product and direct them toward our customers' needs.

Table II shows the positioning of the WPC in the market.

TABLE II. Positioning WPC in the market

Ingredient replacer in existing products
New ingredient in new products
Characterizing agent

1. First is as an ingredient replacer in an existing product. The key to this application is function, economics, and flavor. WPC replaces an existing ingredient in a food, most often the existing ingredient is NFDM. When the WPC provides the same functional characteristics, incorporates compatible flavor profile, and provides the customer economic advantages, WPC has found a new home as a food ingredient.

2. The second area WPC functions as a new ingredient is in new products. This is an area of opportunity in the new product development, where WPC has a purpose in the product with function and flavor.

3. The third area is when whey protein functions as a characterizing agent. By a characterizing agent, I mean an ingredient that provides the basic characteristics without which the new product would not exist. An example of this is some of the citrus products fortified with WPC. The WPC provides an acid soluble characteristic which allows the citric drink to be fortified. Without that characteristic in the whey protein, the end product itself could not exist.

Again, the key in positioning any product is in the listening. When we listen to our customers, we have an opportunity to hear what they really need and to fill that need with one of our products.

If we direct our sales and marketing efforts, we begin to control our marketplace and have the opportunity to cause a product to grown. However, there are some outside factors that will have a tremendous impact on the future of WPC (Table III).

The first influence and effect is the milk supply and cheese production. The Dairy Support Program has been the subject of considerable interest for the past few years. We are now beginning to see some success in controlling the dairy surplus situation with the current diversion program. The USDA is going to keep the cost of the support program down; therefore, components of

TABLE III. WPC future influences and effects

Milk supply and cheese production
Technology
WPC production quantities
Permeate
Regulations

the dairy price program should sell at price levels above the support. Assuming the USDA retains the diversion program or incorporates sufficient incentives to keep production of milk balanced with the demand, we should see a positive impact on the price of cheese and whey products. Whey products including WPC will find better value added markets—once the supply and demand is in balance. Whey prices currently exceed the cost of production. Whey solids utilized in WPC also come in balance with the market. By that I mean that if it takes 3 lbs of whey solids to manufacture 1 lb of WPC (34%), the price relationship between whey and the WPC should be about 3 to 1 or higher depending on the added value of the product. Otherwise, the whey solids used in WPC 34 would have more value as whey powder.

If on the other hand, the milk supply once again exceeds the commercial demand, dairy product surpluses would certainly depress market prices, and we would be looking for volume markets by cutting prices. If this occurs, we have a very good chance of seeing the price of whey come to a level that recovers just the variable cost of production, and the price relationship between whey and WPC would float independently.

The next influence effecting the future of whey protein is the continuing development of technology that will allow us to manufacture products to meet the needs of our customers. Technology will continue to lead demand by providing variations of whey protein concentrate not available in the marketplace today. Examples of this emerging technology and production capabilities are for high protein whey protein concentrates, hydrolyzed protein products, low fat and no fat whey proteins, and products with the lactose hydrolyzed. If this technology is market driven to meet the needs of our customers, we will see a whole new generation of products for new uses and new customers.

A third influence creates an effect we have historically seen throughout the dairy industry, that is the WPC production quantities. Today we can now produce a wide variety of whey protein products. We have good control of our quality; we are now able to produce consistent products and develop repeatability at various different plants. We also produce plentiful volumes. The question we now have: Will the volume that we produce exceed the demand and the rate in which the markets develop? If we produce quantities of these new speciality products beyond the demand of the developing marketplace, we

the dairy industry will create a whole new generation of commodity and animal feed products. I believe it is very important to realize that worldwide there exists about 60 million lbs of high protein, whey protein concentrate capacity. And by that I mean production capacity that can produce 50% and higher whey protein products. The utilization of these products for food uses is estimated to be less than half of the existing capacity for production. We currently have the capacity to mass produce high protein products before the markets are ready.

The fourth issue relates to permeate. This may, in fact, be the most critical issue in the future of whey protein concentrate now or ever. The permeate disposal problem in the 80's will exceed the whey disposal problem of the 70's. The day of the little pipe running out from the back of the plant to the stream is over. Permeate technology must catch up with that of the technology we have for WPC or the tail will, indeed, wag the dog. Today, we have permeate utilization in lactose production; the permeate is used for whey replacer products and permeate is used in various dairy blends. Tomorrow the technology must evolve where practical and commercial uses of permeate in the area of energy production for alcohol, methane, and other products become practical. Chemical production, through various methods of fermentation, also provides an area of opportunity. The technology to develop these products to commercial ends needs to continue. "Some day they will produce WPC just to get the permeate."

The final influence I have listed on my chart relates to regulations. Utilization of whey in other dairy products has long been the nearest, most practical use for WPC. When we look within our own industry where whey protein is most compatible, we find ice cream, yogurts, fortified fluid milk, and many other possible applications. The regulations covering these products could have a major impact on the future of WPC. I won't speculate the impact of what could happen to whey protein should regulations allow the unlimited use of WPC in these areas since the answer is obvious.

The newest and most controversial use of WPC is actually the closest to home we can find ... UF milk for cheese production. In this application, milk is run through a UF process and the whey protein is utilized in the production of cheese. This is probably the best value added opportunity for WPC in today's market. Since this practice is becoming quite extensive and more and more plants are using this system, the impact of WPC on the entire cheese industry is phenomenal. If UF milk became the standard practice and increases our cheese yields by 15%, the impact on the whey industry would be tremendous.

Regulations pertaining to this would be one of the largest deciding factors affecting the cheese and whey industry in our era. Just think what would happen to permeate.

In conclusion, I believe WPC has the potential to be the most exciting, profitable, and society benefiting product of the dairy industry. There are a few ifs. We, as an industry, must become market driven. We must avoid overproduction of new products before the markets are developed. If we are market driven, we sell specialty products. If we are production driven, we sell commodity products. The choice is ours to make.

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SUCCESSFUL UTILIZATION OF WHEY SOLIDS IN ANIMAL FEEDS//

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INTRODUCTION

A search of the literature or the experience of holding the responsibility of utilizing whey solids in A. F. lead one to a myriad of usages.

Whey is fed dry—as an ingredient—in a few commercial feed applications, in quite a few expensive "feed additive" concoctions, as an additive to silages, condensed, ammoniated, and fermented; or fed as a liquid from the vats as is, or condensed.

DISCUSSION

Work was begun by Mid-America Dairymen, Inc., in 1976 to implement profitable uses for whey solids not incorporated into human foods. Literature review and consultations with current researchers led us to USDA-Beltsville where work was being done on making "lick blocks" from UF permeate. Modification of equipment, procedures, and other trials led Mid-Am to the production of a whole-acid-whey solids block, vitamin and mineral fortified and balanced to be fed to baby dairy calves just off the bottle, or as a creep feed for beef calves. The blocks were economical to feed as they were being produced by Mid-Am and sold to its member/owners at the cost of production.

The cost of production of the whey blocks was in line with the costs of conventional feedstuffs; e.g., calculating the value of whey at 67% the value of corn for the energy value and adding 22% the value of soybean meal for its protein value. That price was the approximate price that it was costing to produce the block.

Dried whey prices went back up after we had produced the blocks for about 3 years; mold and other problems persisted, and it was more cost effective to dry the whey than to attempt to get it all into blocks every day.

Dried whey prices, however, as usual, failed to maintain cost effective sales prices, so alternative methods of whey utilization were explored.

Concurrent to Mid-Am's experience with the whey block, research was being carried out by Dr. Rex Ricketts of the University of Missouri-Columbia and Mr. Gus Rutledge, Manager of Hammons Walnut Processors. Hammons and University of Missouri research outlined the probability of successful utilization of liquid whey as indicated herein in Tables I, II, and III.

Treatments were: 1) liquid whey and fescue hay, 2) liquid whey plus a concentrate containing a 14% walnut meal (a byproduct of walnut processing), 3) concentrate containing 14% walnut meal, and 4) a concentrate of corn and soybean oil meal.

Liquid whey provided 49% and 22% of the dry matter consumed by steers on treatments 1 and 2, respectively.

TABLE I. Performance and costs of gain over 124 days

Treatments	No. of steers	Initial weight (lb)	Final weight (lb)	Average daily gain (lb)	Cost/gain[a] ¢/lb
1) Whey + hay	18	655.0	940.0	2.27	12.70
2) Whey + conc.	19	671.0	1,098.0	3.37	34.00
3) Concentrate w/ walnut meal	20	662.0	1,093.0	3.41	42.00
4) Concentrate (control)	20	673.0	1,148.0	3.75	39.20

[a] Hay $30/T, corn $3.08/bu, conc. ration (11%) $116/T.

TABLE II. Carcass characteristics

	Treatment			
	1	2	3	4
No. of steers	18	19	20	20
Final weight (lb)	940	1,098	1,093	1,148
Percentage shrink	-[a]	3.1	3.1	2.8
Dressing percentage	-[a]	62	59	56
U.S. grade	-[a]	18 Good 1 High Good	20 Good	20 Good
No. condemned livers	-[a]	4	0	4

[a] No data. Cattle not finished on this ration.

TABLE III. Liquid whey intake with corresponding average body weight at period end[a]

	Whey + hay		Whey + concentrates	
Periods	Whey (lb./hd./day)	Body weight (lb)	Whey (lb./hd./day)	Body weight (lb)
Initial		665		671
1	98	728	60	815
2	170	809	96	939
3	204	885	81	1,014
4	209	910	59	1,097
Average	170	805	74	907

[a] Ricketts et al., University of Missouri, 1977.

Mid-Am provides tankers for the feeder to haul to the feedlots on a daily basis. The feeder provides the tractor and driver and receives from Mid-Am a very nominal price/cwt, roughly equivalent to fuel costs, to take all the production on a daily basis. Mid-Am in turn could shut down the whey condenser and dryer and reallocate labor to more cost effective duties.

The success of feeding liquid whey hinges in management being able to perform the "art" of liquid feeding. Holstein steers weighing 750-900 lbs are the bulk of the animals fed. They are brought in and processed; i.e., wormed, deloused, vaccinated with 7-way blackleg, lepto, etc., as local health conditions may dictate.

Cattle are started on 5 lbs of concentrate per head per day and have free choice to hay.

After 7 days, the concentrate is gradually increased to 18-20 lbs/head/day at 30 days. Water is offered the first week with whey gradually substituted for water during the second week. This adaptation to whey may be done by providing a trough of each, whey and water, and each day pour one more 5-gal bucket of whey in the water so that by the end of the second week, the cattle are acclimated to the taste and begin normal consumption of whole whey.

After 30 days, the cattle are fed 2 lbs of grass hay and 18-20 lbs of grain per head daily and allowed free access to liquid whey. The cattle have

consumed approximately 225 lbs of liquid whey per head daily in the summer and 150 lbs in the winter.

Hammons experience indicates that it takes about 6 lbs of concentrate per lb of gain in addition to the whey. The feed cost of a lb of gain runs about $0.35.

The Holstein steers gain at the rate of 3 lbs/day to 1,300 lbs when they're sent to slaughter, grade, and yield. They drink whey up to the day they are sent to slaughter. The steers shrink about 4% on the 100-mile trip. They dress out 60% ± 2%. Quality grades have been 60% choice, 38% good, and 2% standard.

Deaths have been minimal. Deaths occur if cattle run out of whey, then have fresh whey delivered. Some individuals will consume the fresh whey, overload, and die.

CONCLUSIONS

A most consistently satisfactory successful utilization of whey solids can be attained by feeding liquid whey to cattle, as liquid, in lieu of water. The whey processor and cattle feeder must strike a good agreement and the arrangements must be adhered to by all. Management of the feeding operation must be top-notch, not only in feedlot husbandry and ration balancing, but in observing environmental constraints of the feedlots and in the disposal of whey in excess of feedlot needs.

If the whey processor chooses to utilize his whey by agreement with a cattle feeder, then he must be willing to trade off some of the negative aspects of drying it at a loss or of hauling it off, for the obligation of provision of a steady fresh supply for the feeder, every day.

WHEY AND WHEY PRODUCTS USE IN BAKERY APPLICATIONS

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I had the opportunity of addressing the 1980 Whey Products Conference, at which time I spoke on the opportunities for whey utilization in the baking industry. In my remarks at that Conference, I suggested that two major events must occur if dairy ingredients are to be used in broader applications and at higher levels in bakery foods.

First is the establishment of technological and functional benefits for adding dairy ingredients to bakery products. I want to discuss this subject in some depth in my remarks today.

Secondly, I expressed the belief that a standardization of whey-based ingredients would facilitate the evaluation and utilization of these products in bakery foods. I will not dwell on this subject today, except to say that I still believe this is true while recognizing that many people would disagree with me.

This is not to say that there is no place for specialized whey-based ingredients in the baking industry—there certainly is. However, if the ultimate objective is to move large quantities of whey products (and there certainly are large quantities available), there must be established an application that probably exceeds the capacity of any one whey processor to supply. The baking industry represents such a potential market—a market that is measured in hundreds of millions of pounds annually.

I understand the economics of specialized ingredients with lower tonnage and generally better profit margins vs. high tonnage, commodity-type products with generally tight profit margins created by competition in the marketplace. The baking industry faces this problem every day with white bread under extreme competitive pricing pressure and specialty baked foods offering the opportunity for more favorable pricing. It is the combination of high volume white bread and lower volume specialty products that offers the wholesale bread baking industry the opportunity for a satisfactory return on investment. Is a similar situation possible in the whey processing industry?

I would like to add a third event which I believe will enhance the utilization of whey products by the baking industry. This would be an increase in marketing efforts by the whey industry to the baking industry based on sound technical data which emphasizes the functional benefits of existing and new whey products in bakery foods.

I conducted a survey of the baking industry in late '82 and early '83. The objective was to determine the attitude of the baking industry toward dairy products as ingredients. I can say that the baking industry is not being overwhelmed by technical marketing efforts from the dairy industry. The development of new products or new information on functional benefits of dairy

products in bakery foods could result in a valuable sales and marketing tool for the dairy industry.

Work at the American Institute of Baking and other laboratories is moving in the direction of addressing all three of these issues and strengthening the hand of whey producers in marketing to the baking industry.

There are a number of bakery foods in which whey products are commonly used as standard ingredients. These applications were initially based on whey solids as an economical substitute for nonfat dry milk. In some cases, whey solids are blended with soy ingredients or other dairy products, including nonfat dry milk, casein, whey protein concentrate, etc. These blends were designed to enhance the functionality of straight whey solids as a replacement for nonfat dry milk.

However, as you well know, dry whey does not have the same functionality as dry milk. The whey processing industry knows this and the baking industry also knows this. This has led the baking industry to move in a number of directions. In some cases, particularly cake-type products, bakers have continued using nonfat dry milk or converted back from whey solids to nonfat dry milk. At the same time, some bakers have begun using blends of whey with other functional ingredients in an attempt to duplicate the functionality of nonfat dry milk. Some bakers have simply reduced the amount of dairy ingredients, including whey solids.

The rapidly rising price of nonfat dry milk during the 1960's and 70's certainly opened the door of opportunity for the whey industry. Bakers were forced to look for substitutes for NFDM or raise their prices to consumers. Whey products seemed to be a natural—a dairy-based ingredient at a substantially lower price. It took some time for bakers to sort out what they could do with the available wheys and blends of whey with other ingredients. The situation seems to be settling down now and perhaps it is time to take another look at how we can enhance functionality of whey products in bakery foods.

The whey processing industry has certainly shown interest in developing products with enhanced functionality for the baking industry.

One area that has received a high degree of interest and activity has been the development of whey protein concentrates. An excellent discussion of this subject was made by Al Hugunin at the AACC Symposium on Dairy Products for the Cereal Processing Industry. As pointed out in this discussion, all whey protein concentrates are not alike even if similar in chemical composition. Whey protein concentrates may cover a broad range in protein contents above the minimum of 25% as specified by Federal regulations. There are a number of methods used in the production of whey protein concentrates, including variations in heat treatment, which will affect functionality of the product.

The most popular method of producing whey protein concentrate is ultrafiltration. This method is basically a physical separation of the components of whey with little or no changes in properties which would result if chemical

or heat treatments were used. Whey protein concentrates can also be produced by heat precipitation under acidic conditions. In this case, the proteins are denatured and functional properties would be quite different from product made by ultrafiltration. Dialysis and polyphosphate precipitation are other methods which might be used to produce whey protein concentrates.

The point is that the whey processor has a number of tools available to him to modify or control the properties of whey protein concentrates as influenced by degree of denaturation, protein molecular weight, pH, ash, lactose and protein content. Water absorption or binding can be increased by denaturing or succinylation of whey protein.

As Hugunin pointed out, low water absorption is preferred for some applications of whey products in bakery foods—for example, protein fortification of chemically leavened cakes.

Other functional properties which can be influenced by processing of whey include emulsification, whipping and foaming, gelation, and rate of browning due to the Maillard reaction during storage or baking.

In discussing the future of whey protein concentrates in processed cereal products, Hugunin said, "The big opportunities for whey protein concentrates probably remain to be discovered." Therefore, the development of functional whey protein concentrates and technical information on their use appears to be a viable approach to the establishment of a significant market for whey products in the baking industry.

The whey processing industry has also looked at other modifications of whey in an attempt to develop functional ingredients. The American Institute of Baking has had an opportunity to evaluate a number of these experimental or commercial products.

For example, we have evaluated an all natural milk replacement system which is derived from a controlled fermentation of whey. Although designed and promoted as a milk replacement system, this material exhibits mold inhibition properties and would be of interest to those bakers desiring to market so-called natural products. Results of our studies indicate that this product, when used at appropriate levels, is equal to chemical preservatives in mold inhibition. It is also equal to or better than other commercially used natural preservatives such as vinegar and raisin juice. Economics may be a factor in broad-scale utilization of whey-based ingredients of this type by the baking industry. However, this development certainly illustrates the potential for developing functional derivatives from whey.

There has also been considerable interest in recent years in the development and evaluation of whey products in which the lactose has been hydrolyzed. Lactose is nonfermentable in yeast-leavened bakery products. Also, it has substantially lower sweetness levels than sugar or corn-derived sweeteners. Hydrolysis of lactose releases fermentable glucose and nonfermentable galactose.

There are a number of options available to the whey processor in hydrolyzing lactose in whey. First, theoretically, the degree of lactose hydrolysis can be controlled from partial to essentially complete hydrolysis. Secondly, the form of lactose can be varied. For example, the lactose in liquid whey could be hydrolyzed. Or certain components of liquid whey such as minerals and protein could be partially or completely removed prior to hydrolysis of the lactose. Or a clear syrup could be prepared by hydrolyzing lactose in an essentially pure solution.

We have looked at several products representing these options. In one case, we looked at a "hydrolyzed whole whey" in which 90+% of the lactose was hydrolyzed. In another instance, we evaluated a whey permeate in which about 90% of the lactose was hydrolyzed. This permeate was high in ash (about 7.0%), but some of the protein had been removed.

Results were encouraging, but by no means final. The hydrolyzed whey products, particularly the whole whey, had a tendency to discolor if stored at temperatures above refrigerator temperature. This undoubtedly was due to Maillard browning of the protein and reducing sugars. There appeared to be no significant adverse effects on mixing requirements, dough handling properties, and proof times. We produced bread of good volume and acceptable grain and texture. The baked products were less sweet than control products due to residual galactose in place of residual glucose or fructose. There was a tendency for bitter and other off-flavors to develop, particularly during storage of the breads.

Additional research on both processing of lactose hydrolyzed whey products and its application in bakery foods might well lead to solutions to the problems uncovered in our limited research.

We might let our imaginations wander a little at this point. Can we visualize a combination system containing sweetener and dairy ingredient in one easy-to-use syrup? Must we keep the product refrigerated or can we find a way to prevent discoloration? The glucose portion of lactose seems to provide the fermentable carbohydrates we need. Will advances in enzyme technology lead to the conversion of galactose to a sweeter form of sugar? What component causes the bitter flavor to develop during storage of bread? If it's minerals, we should be able to remove them—or reduce them to an acceptable level.

Simple questions with perhaps complex answers. But who's to say it can't be done?

AIB has taken another approach in the identification of potential functional ingredients derived from whey under funding by the USDA/ARS and in cooperation with the whey processing industry. We conducted a preliminary, 18-month study on the functionality of whey and whey components in bakery foods. A wide variety of samples were evaluated: sweet whey, acid whey, demineralized whey, delactosed whey, whey protein concentrate, and a nonfat dry milk control. All samples represented commercial production. The samples, of course, varied in protein, ash, and lactose content. Differences in heat treatment during

processing were reflected in differences in ratios of soluble to insoluble protein.

This was a screening study, designed to identify variables in processing and composition which were worthy of further study. In using commercial products, we sacrificed control over a number of factors such as type and source of cheese from which the whey was derived and heat treatment and other processing parameters in the manufacture of the final products. Nevertheless, we felt our objective could be achieved under these conditions. I think they were.

Samples were evaluated in white pan bread for effects on mixing requirements, dough handling properties, and a number of loaf quality characteristics. We also evaluated the bread for shelf life characteristics by taste panel evaluation and changes in crumb firmness as measured by the Instron Food Testing Machine.

Our results indicated substantial evidence that the processing and/or source of the whey products affects their performance as a dough ingredient. For example, differences in effect on dough strength were observed for two sweet wheys which had essentially identical compositions and were both subjected to high heat treatment during processing. Although partial demineralization of whey appeared to be beneficial, we were unable to correlate the presence or quantity of any particular mineral with its functionality in white pan bread.

Crystallization of sugars is important in a number of bakery foods, particularly cakes, cookies, and icings. Our results indicate considerable differences in effect on rate of crystallization and crystal size between the samples tested. In contrast, we saw little differences between samples in emulsification properties.

The data were subjected to response surface analysis, and I would like to highlight some of the results.

Figure 1 shows the relationship between insoluble protein, soluble protein, and predicted Instron force values—a measure of crumb firmness. The higher the Instron force, the firmer the crumb. The graph illustrates that as the level of insoluble protein increases, the Instron force becomes lower—or the crumb becomes softer. In contrast, as the level for soluble protein increases, the Instron force increases, indicating a firmer crumb. These data would certainly indicate the importance of processing of whey as it affects the ratio of insoluble to soluble protein.

Soluble and insoluble protein also has an effect on flavor scores (Figure 2). Higher insoluble protein levels give higher flavor scores, whereas higher soluble protein decreases flavor scores.

Looking at the effect of ash and lactose levels on Instron force values (Figure 3), we see that higher ash levels tend to give a firmer texture as indicated by higher Instron force values. Lactose has a slightly favorable effect on Instron force values, indicating that lactose will inhibit crumb firming whereas the ash will accelerate this process.

Finally (Figure 4), we see that increasing ash content causes a reduction in loaf specific volume, whereas increasing lactose content will increase loaf specific volume.

In summary, the results of this initial study indicate that: ash is detrimental; lactose is beneficial; denatured protein is beneficial; acid wheys are detrimental.

The results of this preliminary study certainly indicate the potential for enhancing functionality of whey products in white pan bread by controlling the processing (heat treatment) and composition of whey.

These results led us to request additional funding from USDA for a continuation of this study. This funding has been approved and is being supplemented by funding from the Whey Products Institute and Dairy Research, Inc. This project will represent a 2-year effort from July 1, 1984 through June 30, 1986. As in the previous project, our work will be guided by input from a project advisory committee consisting of representatives from the whey processing industry, WPI, DRINC, and a colleague at Kansas State University.

The broad objective of this study is the enhancement of the utilization of whey by the baking industry and optimization of the composition of whey in regards to its major components (protein, lactose, and minerals) and heat treatment.

In this second study, we will use samples prepared under carefully controlled conditions at Kansas State University in contrast to the commercial products used in the first study. A single source whey will be used to produce all samples. We will modify heat treatment to vary the ratio of soluble to insoluble protein. We will further process samples to vary the amount of ash and lactose. The study is being set up under a factorial design and results will be subject to response surface analysis.

As in the previous study, we will evaluate the whey samples in white pan bread, looking at effect on processing, bread quality, and shelf life. We will also evaluate the effect of the samples on dough rheology as measured by the Extensigraph, Farinograph, and Mixograph. Obviously, this type of application data will be of most immediate value to both the whey processing and baking industries. However, of perhaps longer term benefit will be the results of some basic studies we are planning on interaction of whey proteins with wheat flour components.

We are optimistic about the potential value of the results of this study to the whey processing industry as well as the baking industry.

The dairy and baking industries have had a long history of a close and mutually beneficial relationship. This relationship has been under strain in recent years. The American Institute of Baking is pleased to play a role in bringing the dairy and baking industries back together in an effective relationship. We certainly appreciate the support of the U.S. Department of Agriculture and the dairy industry in guiding and funding our program.

An increased utilization of dairy products by the baking industry will only occur if functional benefits of dairy ingredients can be economically justified by the baking industry. We believe that we are moving in the right direction toward achievement of that goal.

FIGURE 1

RELATIONSHIP BETWEEN INSOLUBLE PROTEIN, SOLUBLE PROTEIN AND PREDICTED INSTRON FORCE VALUES
(White Pan Bread)

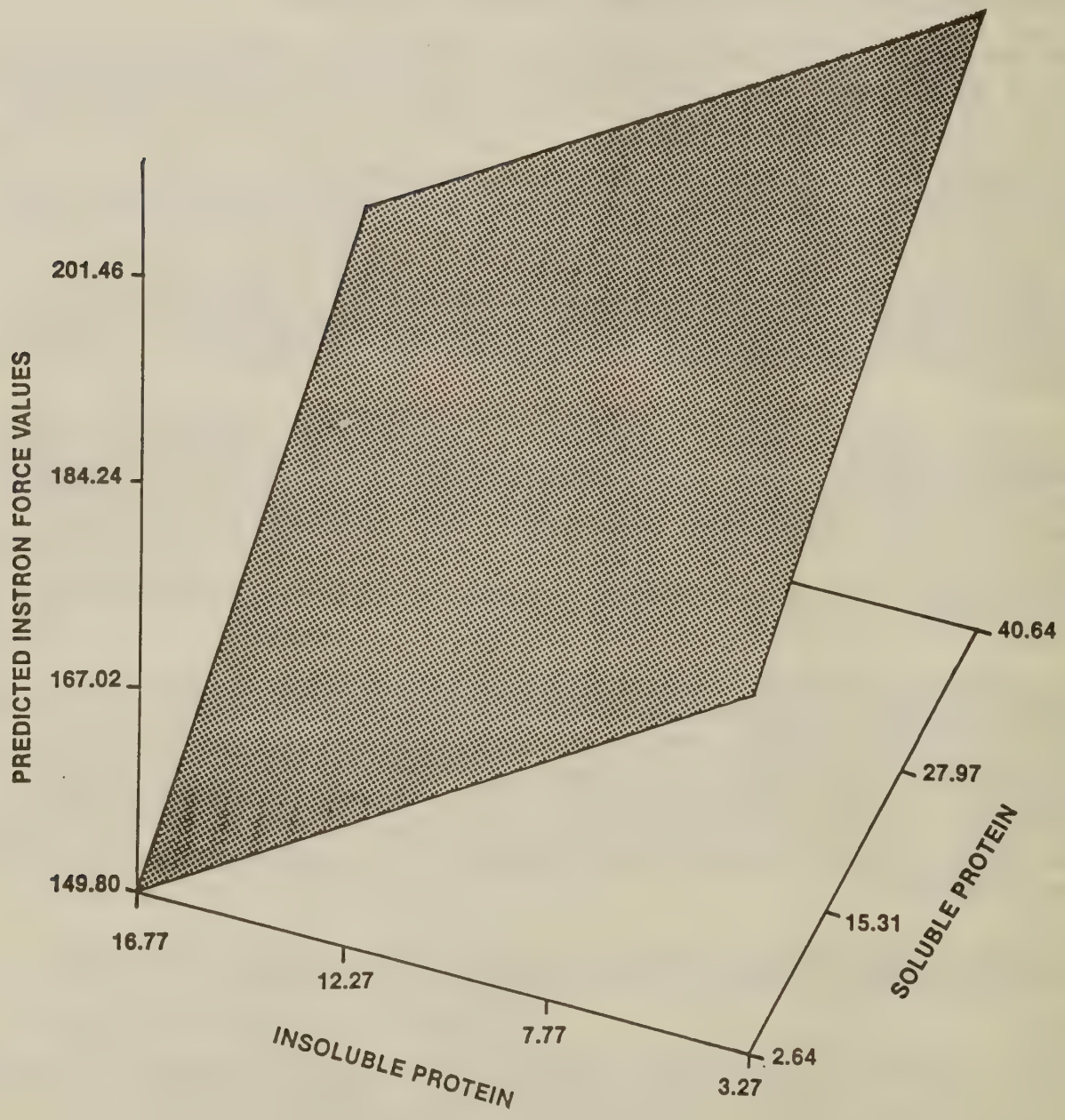


FIGURE 2

RELATIONSHIP BETWEEN INSOLUBLE PROTEIN, SOLUBLE PROTEIN
AND PREDICTED FLAVOR PANEL SCORES
(White Pan Bread)

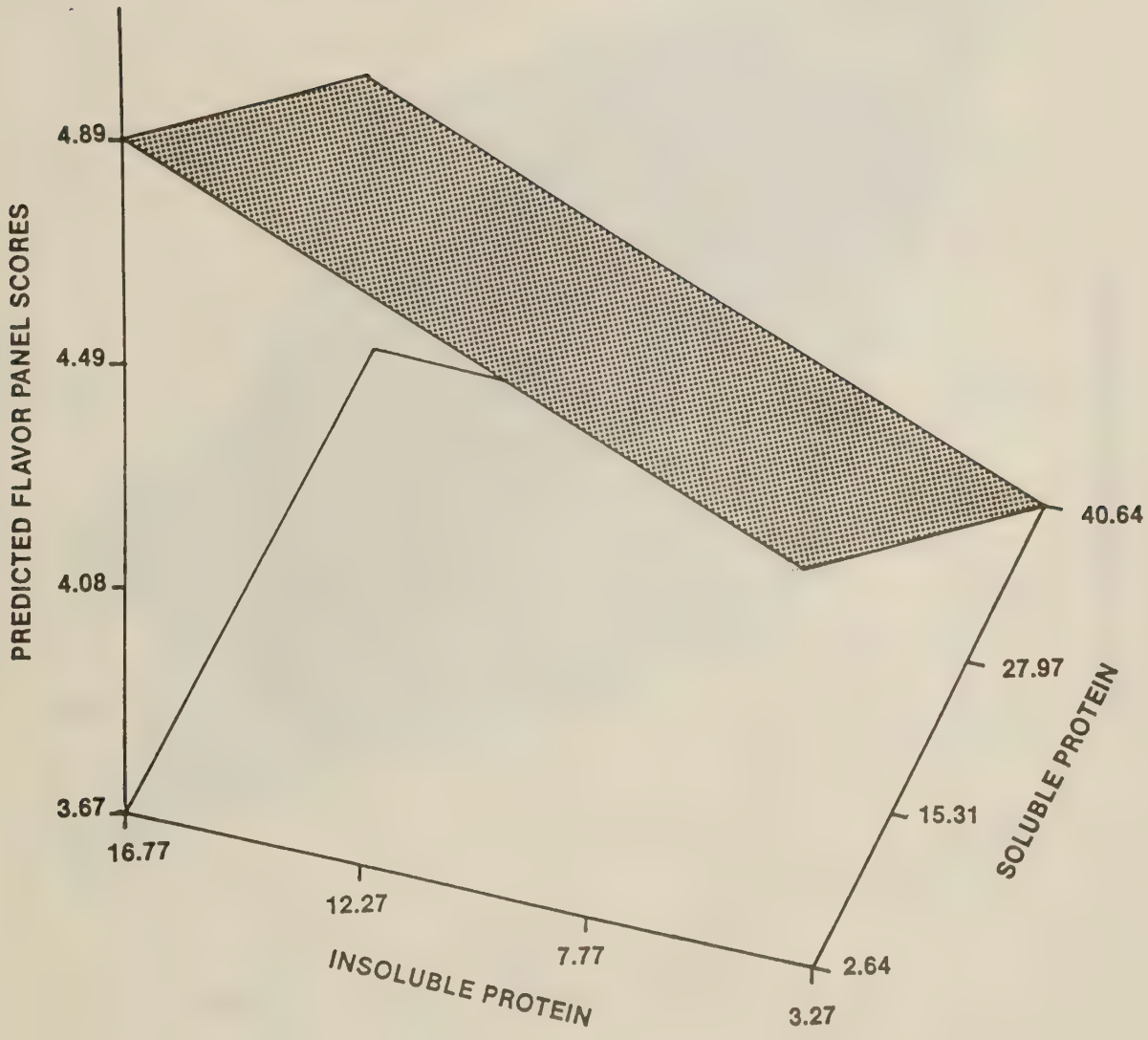


FIGURE 3

RELATIONSHIP BETWEEN ASH, LACTOSE AND PREDICTED INSTRON FORCE VALUES
(White Pan Bread)

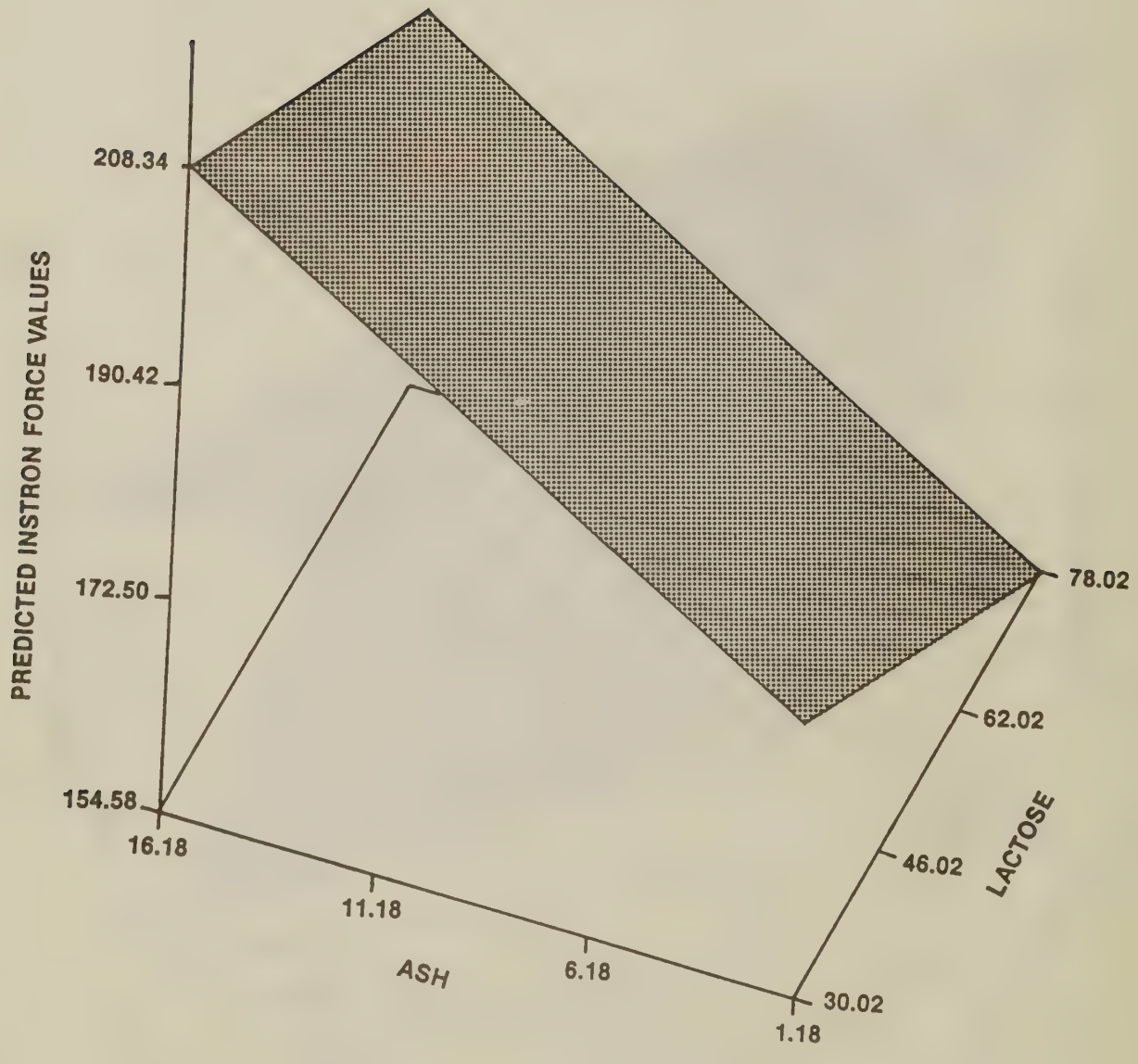
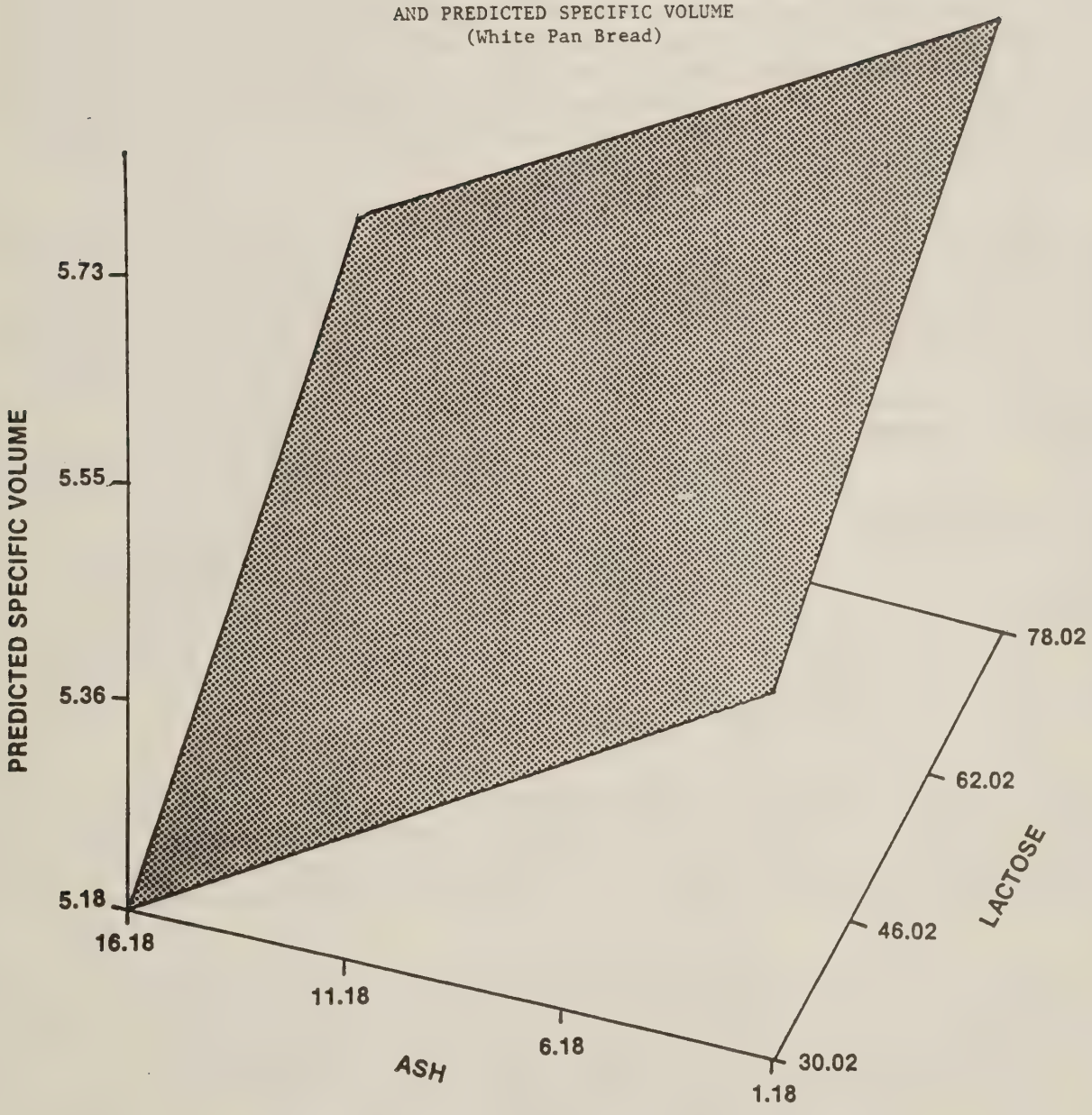


FIGURE 4

RELATIONSHIP BETWEEN ASH, LACTOSE
AND PREDICTED SPECIFIC VOLUME
(White Pan Bread)



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USE PROFILE FOR WHEY PRODUCTS OBTAINED FROM UF-TREATED MILK//

Anthony J. Luksas
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Last year the dairy farmers in the United States produced 140,000,000,000 lbs of milk. About one-third of that milk, or 50,000,000,000 lbs, is processed into cheese, which results in approximately 5,000,000,000 lbs of cheese and 45,000,000,000 lbs of whey. Half of the whey is processed further into food or feed products, the rest or approximately 20,000,000,000 lbs plus is dumped on the fields, land fill, streams, municipal disposal systems; therefore creating a pollution or disposal problem.

The type of products that utilized whey is processed into include concentrated whey solids, dry whey, modified dry whey products—reduced lactose whey, reduced mineral whey, whey protein concentrates; lactose, whey solids in wet blends. According to WPI records, in 1983 a grand total of 1,484,190,000 lbs of whey solids and solids equivalent was processed for human and animal feed. This whey that is utilized in food or feed products comes from the larger cheese plants. The whey that is not utilized in food or feed products or is disposed results mainly from smaller plants that cannot afford to install the necessary equipment to process the whey due to costs constraints or ship it to larger cheese producing plants for processing because of costs in shipping single strength whey. If there was a way to provide the whey processing plant with whey that was more concentrated in total solids, and the concentrated whey would contain less ash and lactose, the cost effective cheese-whey processing plants would be more cost effective. The smaller plants that cannot afford to install the necessary equipment to process the whey due to cost constraints or ship it to larger cheese producing plants for processing because of cost in shipping single strength whey may be able to do so with profit and minimize pollution.

On-farm ultrafiltration has the potential of providing the cheese-whey processors a higher total solid whey with less lactose and ash with the remaining lactose and ash and most of the water remaining on the farm to be fed back to cows as is, or converted to high quality feed by a process to be discussed later.

The proposed on-farm ultrafiltration demonstration project in California will provide the cheese processor that utilizes whey more concentrated whey with lactose and ash reduced. The cheese processor that cannot economically process whey into salable product today, may be able with the on-farm ultrafiltration to now process their whey into salable items economically and by doing so eliminate or minimize pollution. The successful and wide-spread application of ultrafiltration technology will go a long way in eliminating the 20,000,000,000 lbs plus whey disposal problem by leaving the lactose and ash stream on the farm to be fed back to the milk-producing cow.

The milk destined for cheese production does not have to be ultrafiltered on the farm, but in order to realize the savings that are anticipated and the

potential whey products, the initial ultrafiltration to 50-75% volume reduction should be done on the farm. If a farm has less than 100 milking cows, the ultrafiltration may be best done at the collection station and if the collection station is the cheese factory, then the total process can be established at the cheese factory.

It is premature at this time to go into details as to the economics since the California on-farm ultrafiltration process was just started.

In order to position the on-farm and related ultrafiltration in its proper perspective, I will review briefly with you the UF process that we will be using. Ultrafiltration is a separation process that can be used for selectively separating biological components in liquid mixtures. Ultrafiltration as a commercial process has been in existence since 1968, but has not been utilized extensively in food manufacturing until the advent of present day membrane developments. Present-day membranes introduced about 10 years ago are produced from polysulphone polymer, which makes them highly durable and cleanable by dairy cleaning chemicals. The ultrafiltration systems have been in operation at food and dairy plants for at least 8-10 years. These operations have demonstrated that ultrafiltration membranes are durable under plant operating conditions and cleaning regimes with acceptable longevity. Ultrafiltration membranes normally carry a one-year warranty, and are relatively inexpensive to replace. It is not unusual to see UF membranes operating two years without replacement.

The membrane basically is a very, very fine screen or sieve that screens at molecular levels. It has the capacity to enrich the protein stream like milk by allowing water, lactose, soluble salts, and nonprotein nitrogen as free amino acids and small polypeptides to pass through or permeate while retaining the proteins including whey proteins. A liquid stream enriched in proteins but still containing some lactose, soluble salts, and nonprotein nitrogen as free amino acids and polypeptides is called concentrate or retentate. For example, milk that has half of its volume removed by ultrafiltration has two-fold increase in protein content and approximately half of its lactose and approximately half soluble salts and other small molecules removed. This ultrafiltered milk by virtue of having half of its volume removed, is less expensive to transport or can be transported twice the distance for the same cost and can be used for cheese manufacture. Since half or more of its volume of milk has been removed, loss of milk components during cheesemaking is reduced. The advantages to the cheesemakers that ultrafiltered milk provide include more cheese made in existing equipment, less rennet required, less whey to dispose, and potentially more cheese yield. In ultrafiltration, fat does not permeate, and therefore remains with the protein. Since considerable amount of calcium and phosphorus is bound or trapped in the protein, it too remains in the concentrate.

Milk can be ultrafiltered beyond the half volume levels; concentrates have been made that have been ultrafiltered to composition of cheese. These concentrates have been called pre-cheese, since the composition resembles the composition of cheese. By culturing these pre-cheese concentrates with lactic cheese cultures and adding rennet, cheese consistency can be produced with almost no whey. Conversion of pre-cheese milk concentrate into cheese

requires specialized cheese processing equipment and lends itself more to continuous cheesemaking processes. For many reasons, pre-cheese milk concentrate produced any place other than in the cheese plant is not advisable at present.

Production of ultrafiltered milk by removing half or three-quarters of the volume appears to be feasible at the source of milk production.

Ultrafiltration has been explored as a fractionation process at the university and in industry. Ultrafiltration has been applied to milk for fractionation at Cornell, University of Wisconsin, as well as Utah State University. Due to the results obtained, Dairy Research, Inc. (DRINC) supported on-farm ultrafiltration at Cornell under the direction of Dr. Robert Zall. Objectives in that evaluation were to determine if a UF system can be operated on a university farm daily; also if the resulting fractionated milk would in fact be usable for cheese production. The Cornell study showed that by fractionating milk up to twofold level (or half volume reduction), that Cheddar and cottage cheese can be made with good results. When milk was concentrated more than twofold, it tended to become unsuitable for use in making cottage and Cheddar cheese using conventional methods for cheese manufacture.

Due to exceptional results obtained at Cornell, it was decided to evaluate the process on a real dairy farm. The farm had to be large enough to provide quantities of ultrafiltered milk that could be transported and segregated all the way to the cheese plant; commingling with unprocessed milk (not ultrafiltered milk) had to be minimized. The cheese processor also needs sufficient quantities of ultrafiltered milk so that he too could isolate the ultrafiltered milk/cheese batches from the rest of the production.

The dairy farmer chosen in California met these requirements. The farm is also in close proximity to four cheese processors that produce Mozzarella, Monterey Jack, Cheddar, and Brie.

The process of on-farm ultrafiltration is no more different than what transpires during cheesemaking. In ultrafiltration, nothing different takes place other than is accomplished in a cheese manufacture except that the cheesemaking process starts at the farm and is finished in the cheese vat. But, since this process is new and different as compared to present day milk processing, we felt that the regulatory agencies in California and Washington should be informed and involved. The project has been discussed and permission was granted from the California Department of Food and Agriculture, Bureau of Milk and Dairy Foods Control, to produce the ultrafiltered milk on the farm, then transport the ultrafiltered milk to the cheese plant, process the ultrafilted milk into cheese, and sell the resulting cheese within the state of California. We also discussed the project with FDA, and they indicated that at this time since there is no data to indicate that the cheese made by this process is not different composition-wise, nutrition-wise, and acceptable by the consumer, they also would not want to see the cheese cross state lines. As long as we produce and sell the cheese in California, they would not interfere. They also indicated that they will eagerly await the analytical and sensory results to determine if in fact the cheese resulting from ultrafiltration is well within the statistical range

anticipated for that cheese. They further indicated, based on the data generated, that they would decide whether the cheese standards need to be amended and to what extent to provide for interstate shipment of the cheese made from ultrafiltered milk.

The objectives of the on-farm ultrafiltration are:

1. Establish the ultrafiltration process on-farm and seek FDA approval to use the ultrafiltered milk in cheese manufacture.

2. Determine if commercially acceptable cheese can be made from the ultrafiltered milk.

3. Determine value added worth to the farmer and economics of the process.

4. Determine if the ultrafiltration system can be operated successfully on a real operating dairy farm every day for one year.

5. Determine if ultrafiltered milk will require specialized transportation equipment.

6. Seek USDA approval of the process.

If the ultrafiltration process is implemented on the farm to partially fractionate the milk for cheese manufacture, the effect will be a restructuring of the industry. Let us examine this statement further.

From the data generated to date at Cornell University by Dr. Zall as well as data generated in European operations, the following can be expected if one fractionates milk on the farm.

The resulting concentrate at 50% volume reduction should save on transportation. Preliminary indications are that if a 100-cow farm produces 60 lbs of milk per cow per day, or 6,000 lbs, and milk shipping cost is 60¢ per mile and the milk is shipped 100 miles, the UF investment can be paid off in 3 years just on the transportation cost.

A cheesemaker should save in labor and equipment and quality of cheese produced. The cheesemaker can make twice as much cheese with the same labor or equal amount with half of the labor and equipment. The cheesemaker also as a result will have a better quality whey either to sell as is to larger whey manufacturer or now be able to process the whey himself due to higher solids and better composition for quality and better return on investment.

Milk ultrafiltered to 50% volume reduction has the following composition. The concentrate has 100% of the butterfat, 99% of the protein, 50% of the lactose, 65% of the ash, and 37% of the original milk volume. The permeate contains 0% fat, 1% protein, 50% lactose, 35% ash, and 63% water. These figures are reasonable averages from the data generated so far, but should not be construed to be absolute.

Taking milk composition as shown in the next slide and applying the percentage for concentrate and permeate in the previous slide, the resulting calculated composition of concentrate contains 3.7% butterfat, 3.27% protein, 0.455% ash, 2.35% lactose, and 32.4% water, while the permeate contains no fat, only a trace of protein, 0.245% ash, equal amount of lactose, and 55.2% of the original water.

The data in the next slide is actual data resulting from the ultrafiltration project at Cornell. The data shows that the whey contains twice as much protein, some lactose content as normal whey, slightly more ash, and twice as much fat.

As can be seen from the established gras (whey and whey products) and their compositions, the new ultrafiltered milk whey from 50% percent volume reduction concentrate has an interesting profile. The protein content is on the high side of the reduced lactose or mineral reduced whey. The lactose content is almost equal to the reduced lactose whey, and the ash content is almost as reduced as mineral whey. The total solids content of the new ultrafiltered whey is around 11%. All of these attributes result from the use of the ultrafiltered milk at 50% volume reduction in cheese manufacture. To produce a whey product with these properties from present whey is costly. This new ultrafiltered milk whey being almost 11% total solids provides almost half the concentration cost savings since going from 6.5% total solids whey to 13% total solids whey in concentration requires the removal of 50% of the water.

Any further pre-ultrafiltration either at the farm or at the cheese plant providing the milk does not approach the three-quarter volume reduction, can provide whey streams that will fit the standards of identity of gras whey products.

The widespread application of the on-farm ultrafiltration technology as well as further ultrafiltration at the plant can provide the cheesemaker with the necessary composition of whey for resale at a profit. The permeate resulting from the ultrafiltration of milk at the farm can be fed back to the milk-producing cow or converted to high-quality feed. If the permeate is fed back to the cow as is, it provides energy in the form of lactose (the milk sugar), and some minerals and micronutrients as well as good quality water.

Application of the Single Cell Protein (SCP) technology to the permeate provides the opportunity to the dairy farmer to produce a high-quality feed that he has to purchase from outside.

The microorganisms of choice for the conversion of permeate to (SCP) are the fungi since they produce large amounts of high quality protein, are low in nucleic acids, easily cultured and grow relatively fast. The disadvantage of a high nucleic acid level is in the uridine content of the RNA which can be metabolized to uric acid with the potential hazard of the fed animal developing gout.

The fungus of choice is Aspergillus oryzae since it is approved for food use by FDA. Many of the food enzymes are derived from Aspergillus oryzae. It is the organism that is used to pretreat the grain for soy sauce manufacture.

Laboratory trials have shown that Aspergillus oryzae can, in 12 hr, metabolize a 3% solids permeate feed stream to produce a mycelial biomass (equivalent to approximately half of the solids) of 40% protein, with good amino acid profile, low in nucleic acid content and low fat content, while at the same time reducing the BOD_5 of the permeate by over 95%.

Plans are underway to scale the process up as the schematic indicates to pilot level to produce 300 lbs per day of dried animal feed protein or SCP. The purpose of this pilot system, in addition to providing the process scale-up and finding optimum operating conditions, is to provide sufficient product for dairy cattle feeding studies to be carried out at Utah State University, Logan, UT. The (SCP) product will be fed over a series of trials in three forms: liquid slurry (4% solids), dewatered cake (35% solids), and dried (90%). These trials are designed to determine feed efficiency, impact on milk production, composition, and flavor. The economics of a single cell protein production process from cheese whey permeate at 20¢/lb of SCP, and 100,000 gal of permeate per day capacity, are very favorable.

As can be seen in the next slide, an initial capital investment of $300,000 plus annual cost of approximately $108,500 yields pre-tax income in excess of $1,500,000.

An SCP system designed to process 10,000 gal of permeate would be about one-tenth as expensive and one-tenth as profitable.

At present, it is anticipated that the smallest system which can be cost effective or the capital investment can be repaid in less than 3 years is 1,000 gal permeate capacity system. In all situations presented, the cost of permeate is taken as zero cost.

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THE WHEY PROCESSING INDUSTRY—TODAY AND TOMORROW//

Don Storhoff
Wisconsin Dairies
Baraboo, WI

REVIEW

Milk production in the United States has advanced to record levels. The 1983 record of 139 billion lbs shows an increase of 20% over the past 10 years.

Milk directed to the production of cheese has increased at a rapid rate during this same period. In 1983, 41 billion lbs of milk or 29% of all milk produced was utilized in the manufacturing of cheese.

Production of whey and whey byproducts has also experienced a similar trend. Our industry has increased output of total whey solids to a record level of 1.5 billion lbs of solids in 1983. However, our percentage of utilization remains consistent at about 63%. The major change over the most recent years is within the mix of products produced.

Current utilization of our major classification is as follows:

Dry whey	60.6%
Lactose	9.1%
Wet blends	8.2%
Concentrate	8.0%
Modified products	6.3%
Whey protein concentrate	5.4%
Reduced minerals	2.4%

TODAY

Milk production has been reduced. After 57 consecutive months of increased production, March 1984 began a downward trend that is projected to yield a drop in 1984 production of approximately 3%, or about 135.5 billion lbs of milk will be produced this year.

We have experienced national legislation that for the first time placed an incentive before dairy farmers.

This reduced production along with increased consumer consumption is making 1984 a transitional year for producers and processors.

Another factor in 1984 is the regional shift in milk production.

The West Coast continues to show slight increases while the Southeast leads the Nation in reduced production. This has one major effect on our whey industry as milk from the Midwest which in the past would be converted into cheese now is shipped via tanker to the class I market in the South.

1984 Whey production and the value of whey products has been the result of some of these events. During the period of the heavy milk production period, our whey market was very depressed. However, during the past 6 months, more favorable prices have developed and prospects for a strong final quarter in 1984 seem quite promising.

TOMORROW

A greater percentage of the whey will be processed. The basic reason for the increased utilization is that the milk processed into cheese will be in larger plants with whey processing facilities.

Reduction of the smaller cheese factories who presently are field spreading will support this trend throughout the 80's.

Milk to cheese production will continue to increase. However, a major development in the manufacturing of cheese could affect our industry. The industry technology that will allow certain type cheese to be made via the ultrafiltration method will change the byproduct from what we know today as whey to something quite different in composition. Our whey industry will be watching this development with a great amount of interest.

Our industry is just becoming of age. We have a major character change before us; one from an industry with an environmental disposal problem to one of high technology producing a product of high quality and nutritional standards.

It is significant because our future processing and marketing will take a new dimension.

Through the work of the Whey Products Institute, our safe and suitable status for the use of whey and whey byproducts has been accepted. We shall see expanded use of all whey products. Whey protein in 35%, 50%, and 75% concentration will become more integrated into food formulas. The technology that has brought our industry the membrane process will continue to develop highly efficient systems with longer life and greater cleaning and sanitizing capabilities.

Whey base infant formulas continue to offer great potential. Increased demand for reduced mineral levels in our whey products will expand into additional markets throughout the food industry.

Again, different processing technology is available to prepare product to specific product standards and functional characteristics. Our lactose industry will also benefit from additional demand. Currently new studies are being conducted to determine what is the answer to people who are subject to a low tolerance of lactose. Research will give us ratio levels which we will formulate product to allow increased consumption of milk sugar.

Production lines will become more efficient with the development of better crystallizing methods.

Dry whey is still our largest selling product. Currently, 61% of our industry sales is in the form of whole whey powder. The demand has been increasing at about 100 million lbs annually for the past 4 years. Continued use of this product will be in the food ingredient formulas. However, we may not see the increased use at the same rate of 10%, but a more gradual growth of 5% during the rest of the 80's.

What will determine what lies ahead in our whey industry? I suggest four areas to watch:

1. National dairy legislation.

2. Development of cheese base products.

3. Greater volume of cheese and whey produced in fewer facilities.

4. Expanded use of high added value whey byproducts.

How will we remember the whey industry of the 80's? As the era in which processing technology provided the product to meet the need of our consumer.

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LACTOSE HYDROLYSIS OF WHEY PERMEATE USING A CONTINUOUS FLOW-THROUGH IMMOBILIZED ENZYME SYSTEM//

Alexander G. Hausser
Amerace Corporation
Hackettstown, NJ

INTRODUCTION

Approximately 18 months ago, Amerace reported at the breakfast session of the Whey Products Institute meeting in April 1983 of our lab development work on a continuous immobilized enzyme reactor for hydrolyzing lactose or lactose in whey permeate. Since that time, we have scaled-up the system to the pilot level and commercial design level. It is our objective today to update you on these systems.

There was approximately 5.4 billion lbs a year of cheese produced in the United States in 1983. The industry has a tremendous volume of whey to handle when one considers that for every 10 lbs of milk used to produce a pound of cheese, there is also 9 lbs of whey produced, or about 48 billion lbs per year. Approximately half of this whey is presently disposed of as a waste stream. The other half is dried in some cases to produce whey powder, delactosed to produce lactose and whey, evaporated to produce a syrup, or fractionated via ultrafiltration to produce whey protein concentrate and permeate.

The permeate is a watery solution that contains the milk salts and lactose. If ultrafiltered milk is used to produce cheese, it too produces a milk permeate stream similar to the whey permeate stream. One asks the question, "What do you do with the permeate?" In some cases, it is discarded as a waste stream, and in others, it may be concentrated, dried, and used as an animal feed or fermentation media. We propose that it be hydrolyzed to produce a sweetener substitute, fermentation media, or chemical feedstock.

Amerace Corporation has developed an immobilized enzyme technology that allows us to hydrolyze lactose or lactose in whey or milk permeate into glucose and galactose. This process and the marketing of it has been licensed to the Damrow Company of Fond du Lac, WI, and is marketed under the Damrace (trademark) name. Our objective today is to discuss this process with you.

Enzyme Support Material

Many of you are familiar with the use of the enzyme such as rennet to produce cheese or lactase to hydrolyze milk, whey, or permeate by a batch process. The process that will be discussed today is a continuous process based on an immobilized lactase enzyme. The immobilized enzyme route helps to reduce cost as the enzyme is used many times before it is discarded and does not remain with the finished product.

The enzyme must be bound to a support and Amerace uses a microporous plastic sheet that it produces. Most past immobilized enzyme systems made use of

either packed columns filled with organic or inorganic support material or used ultrafiltration devices where the enzyme was separated from the feedstock across the membranes. The feedstock containing a material of lower molecular weight would diffuse through the membrane, react with the enzyme, and then diffuse back out through the membrane.

The major disadvantage of the bed systems lies in the fact that the enzyme is usually bound inside the bead, which reduces its efficiency since the substrate (feed) must diffuse into the bead to react with the enzyme and then diffuse back out again. This reduces the reaction rate. Beds are noted for uneven liquid distribution which results in channeling and again less efficient use of the enzyme. Since packed columns are made up of bead type materials, they offer a handling problem on filling and discharging the column.

The Amerace System uses microporous plastic sheets that are about 20/1,000 of an inch thick, made of PVC and silica. These sheets are about 80% porous and have a very large surface area. Therefore, large quantities of enzyme can be chemically loaded onto the sheet. The enzyme is bound to the outside of the silica and the substrate (feed) comes into intimate contact with it without the diffusion problems that exist in bed systems. This results in high utilization of enzyme, faster reactions, and smaller reactors. The

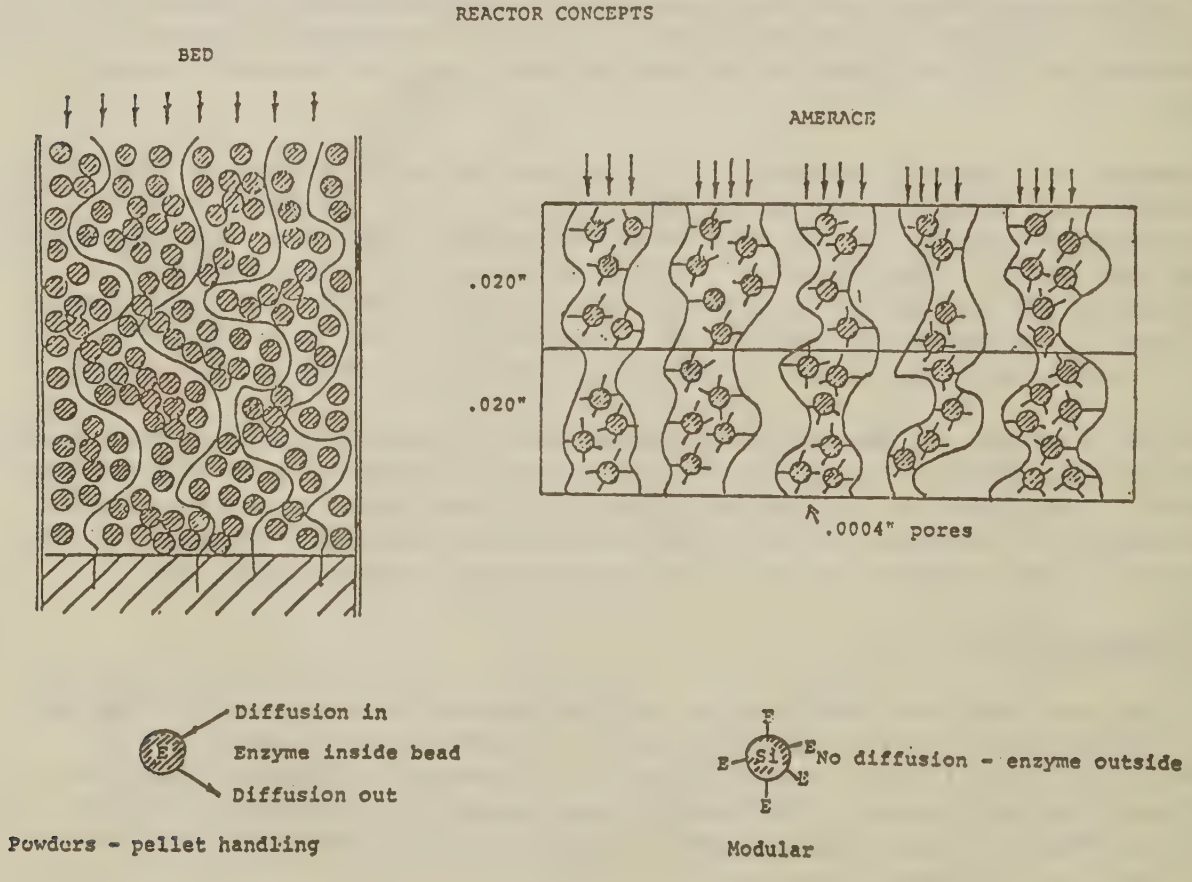


Figure 1.

microporous plastic sheets are stacked upon each other to form a module. The modules are much easier to handle as compared to pellets or powders in a packed column system. (Figure 1 illustrates the above phenomena.)

The thickness of the module is a function of the reaction kinetics. The kinetics determine what the residence time must be for the reaction to proceed at a fixed set of conditions of temperature, pH, and concentration. Modules are placed between support or feed plates (see Figure 2), and then placed in a reactor press. The modules are placed in series in the press, and the flow is in parallel into each module. If production is increased, more modules can be added and if production is reduced, a certain number of modules can be removed. As you can appreciate, the handling is much easier than components used in bed systems.

The Effect of Lactose Concentration

One parameter that is important from a reactor design standpoint is the concentration of lactose in the feed. As you can see from Figure 3, a 5%

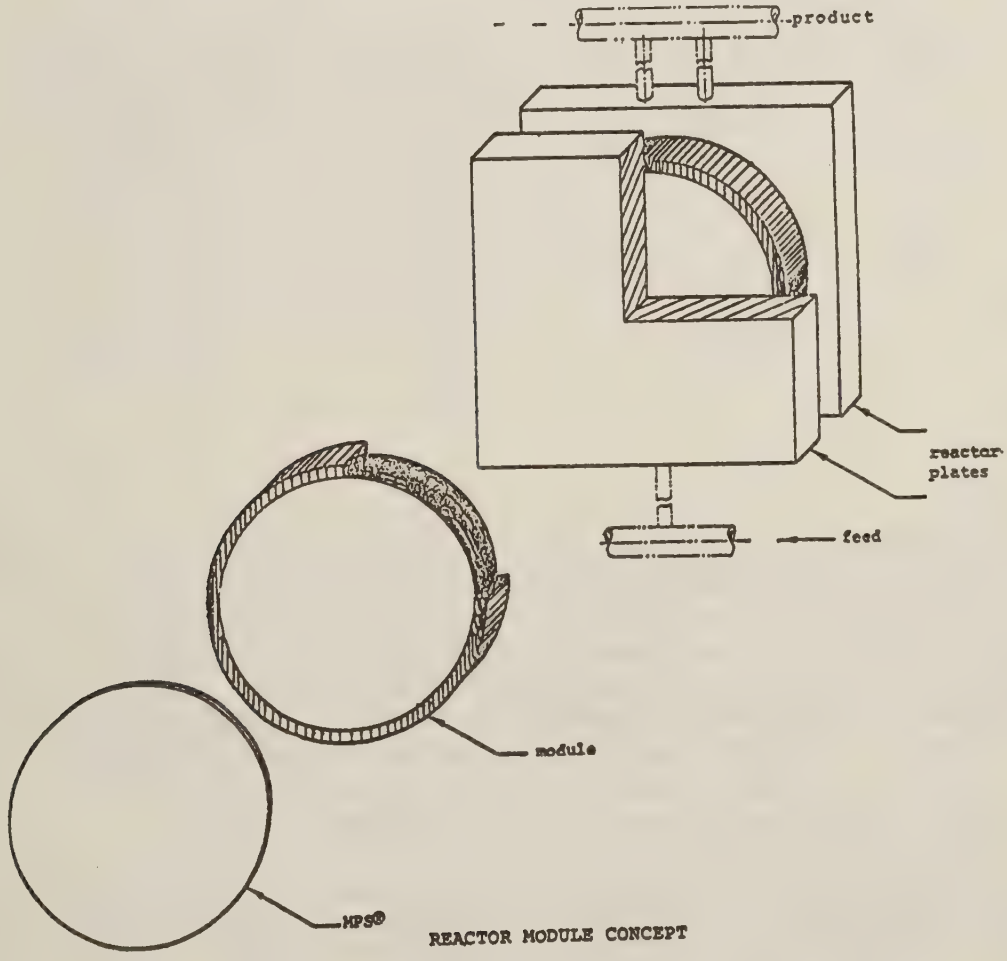


Figure 2.

feed requires 1.5 min residence time in the reactor to achieve 90% hydrolysis of the lactose, and only 42 and 24 sec to achieve 80% and 75% hydrolysis, respectively. If one increases the feed to 10%, the residence times increase to 4.5, 2.0, and 1.4 min, respectively. One notes that as the feed solids increase, the reaction rate slows down. Therefore, from a reaction standpoint, a 5% lactose concentration gives the higher rate, but even 15% concentrations are feasible but not as economical since a large reactor is involved. However, the greater reactor economics may be offset by the potential savings in steam in removing less water on evaporation.

TABLE I. Residence time vs. solids at 90%, 80%, and 75% conversion

% Solids	90% Conversion residence time, min	80% Conversion residence time, min	75% Conversion residence time, min
5	1.5	0.7	0.4
10	4.5	2.0	1.4
15	7.8	4.0	2.2
20	15.0	7.0	4.0
25	20.6	11.0	7.4
30	32.0+	13.6	10.0

Pilot Reactor

The Damrace hydrolysis process was scaled-up from the lab to a pilot system. Where the lab unit uses a module that is about 2 in. in diameter, a pilot unit uses a module 12 in. in diameter. The pilot plant allowed us to finalize our engineering design for a commercial unit and at the same time was used for customers to try out their feedstocks. Pilot plants are now available from Damrow for the industry to evaluate the process in their plants and to produce products that can be used for market development activities. Three 1-month trials at 3 different whey plants using commercial feedstocks have been run on the Damrace pilot system with excellent results.

The following (Figure 3) is a schematic of the Damrace process as used in a pilot plant. The permeate is first ultrafiltered polished. The reason for this is that permeate from one commercial plant to another varies considerably in their quality due to the residual protein in it. The reason for the various quality levels of commercial permeate is due to how efficiently the operation is run. In some cases, membrane sealing can be a problem; in others

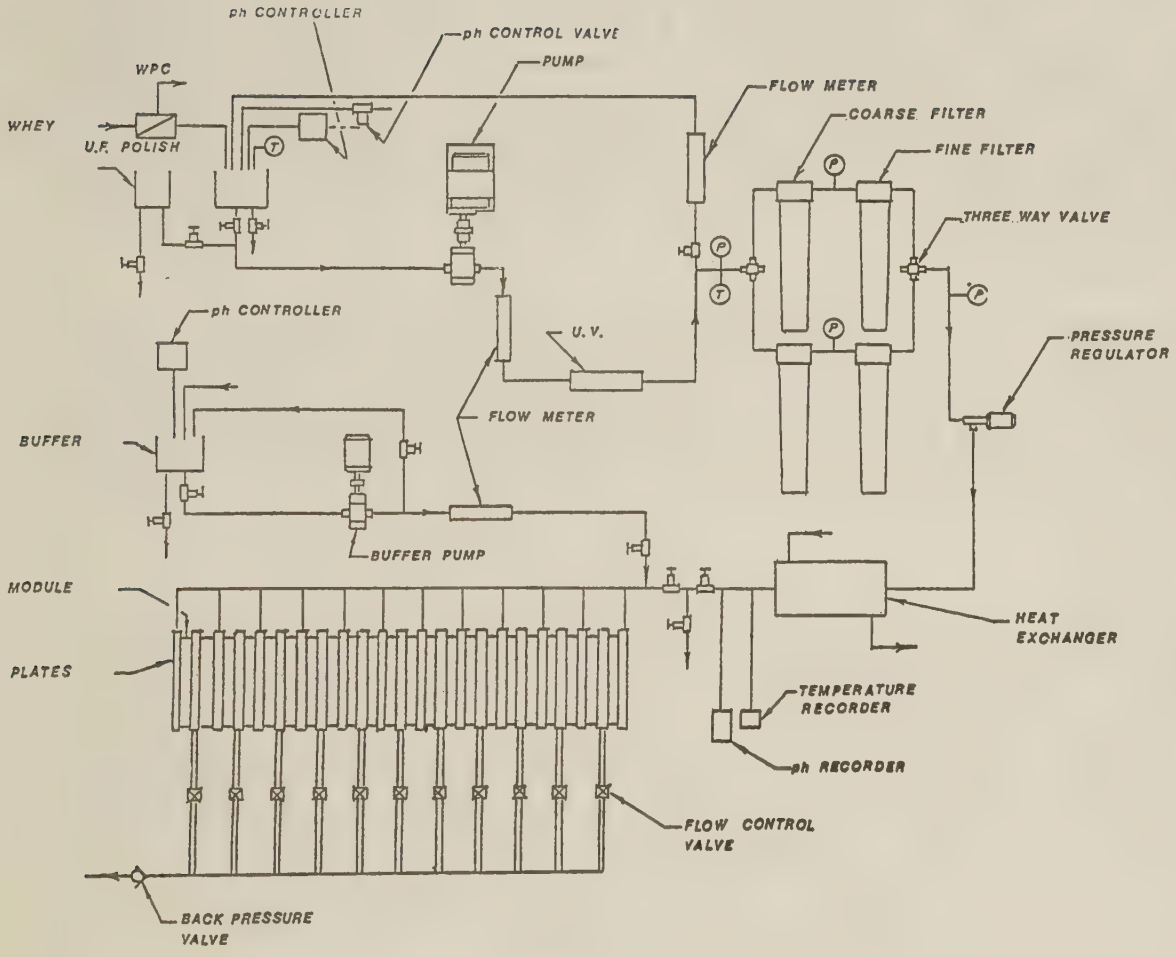


Figure 3.

as the membrane ages, one gets bleed-through of protein; and in others, membranes crack. In order to be assured of a consistent quality feedstock to our reactors, we polish ultrafilter the permeate to remove the traces of protein, a lot of the bacteria but possibly not all, and other suspended matter that may be in it. This UF unit is an order of magnitude smaller than the UF system used in the protein plants since the quantity of protein to be removed is very small. This results in very high fluxes which lead to small surface areas in the UF units.

The ultrafiltered polished permeate is then passed through an on-line turbidity meter to monitor the clarity of the feed and to make sure it is in spec. This assures us that the reactor will have a consistent feedstock and that the product produced will always be of consistent quality free of protein. The feed then passes to a hold tank where its pH is adjusted to 4.5 and then through an in-line ultraviolet unit (UV) to reduce the tendency of bacterial growth. A portion of the UV-treated feed is recycled back to the feedtank and

a portion is fed to the reactor. We have found that with clear feedstocks, the UV unit does a good job in reducing bacterial growth. The feed then passes through a heat exchanger to be either heated or cooled to the reaction temperature. It then passes through a 2-micron cartridge filter to remove any suspended matter and then through a 0.45-micron filter to remove anything that passes through the 2-micron unit. Our experience has been that the 2 micron filter takes out the majority of the suspended matter and the 0.45-micron acts as an insurance policy. The 2-micron filter can be cleaned and reused for a few days. The 0.45 micron can be cleaned and reused as long as the reactor modules are still active. For the pilot unit, this is about 2,000 hr; and for the commercial unit, about 5,000 hr.

The feed's pH is checked once again before it enters the reactor. The feed to the reactor comes into a common header and branches off into parallel streams, such that each module gets the same equal flow. You will note that the modules are in a press and in series, but the liquid flow to each is in parallel. The exit flow from each module goes into a header that takes the hydrolyzed product away.

System Cleaning

A shutoff valve exists before the reactor to isolate it for cleaning. When this valve is closed, one cleans all the hardware. The equipment before the reactor is cleaned by the standard cleaning in place process (CIP) using alkali, acid, and bleach. One cannot use these solutions to clean the reactor modules because they will kill the enzyme. While the front end of the hardware is being cleaned, the reactor modules and reactor are cleaned with a buffer solution of sodium acetate containing a bacteriacide. This solution cleans the modules and reduces the potential for bacteria growth. If one wanted to do further cleaning, once a week for instance, one can take the buffered modules out, place them in a refrigerator, close the press up, and clean it in place with the normal CIP procedure.

A typical pilot reactor press is about 8 ft long by 1.5 ft wide and is capable of handling up to 3 gpm of a 5% feed, 2.0 gpm for a 10% feed, and 1.5 gpm for a 15% lactose feed concentration. Since we have standardized on a pilot press length only for the pilot plant, one does not get equal maximum flow for each feed concentration because the module thicknesses are different. A 5% feed requires only a 0.7 in. thick module. As you can see, a relatively small area is required on a pilot basis to produce a significant amount of product. The last slide shows a picture of the pilot reactor. Here again, you can see how compact it is.

Commercial System

Since the modular design of the flow-through reactor is directly scaled-up, the data obtained on a 2-in. diameter lab unit or a 12-in. pilot unit will be valid for the 29-in. diameter commercial module. A commercial plant would be very similar to the pilot plant except it would have more automated controls. The reactor press size for a commercial plant may be 12 ft long by about 3 ft wide. Depending on capacity, one would have a number of them in parallel.

It is estimated that the hardware cost for a complete Damrace hydrolysis system to handle a 1 million lb/day wet permeate stream at 5% solids would be in the range of $900,000. The immobilized enzyme module cost would be around $210,000 and would last 5,000 hr at the exposed temperature of 30°C. A total processing cost, including 10-yr depreciation and immobilized enzyme module replacements, would be around 3.0¢/lb total solids. If evaporation and/or demineralization are required, the total cost will increase. Evaporation to 70% would be about 2-2.5¢/lb direct operating cost without depreciation, and ion exchange another 3¢/lb. Therefore, total syrup cost is about 8-9¢/lb total solids.

One can now have an economical process to hydrolyze lactose as is or in permeate to glucose and galactose. The potential exists to convert what was a waste stream into a partial sweetener replacer at a lower cost than sucrose or high fructose, as a more efficient fermentation media than lactose, whey, or molasses, or as a possible carbohydrate raw material chemical feedstock. In some cases, demineralization would be required and in others it would not be required. Those of you who were at the 6th Biennial Cheese Conference at Utah State University at the end of August will remember tasting ice cream made from hydrolyzed, demineralized permeate that came off the Damrace pilot unit. This ice cream was sweet and smooth and the hydroperm replaced some of the sucrose. When one considers that sucrose is at 30¢/lb and high fructose at 20¢/lb, a product whose cost is a 8-9¢/lb could be priced to be competitive in the sweetener market. The fermentation market would not need a demineralized product, and therefore, hydroperm may cost around 5-6¢/lb total solid.

The Damrace System is now available through the Damrow Company for piloting or commercializaing a hydrolyzed permeate process.

PRODUCING VALUE—ADDED WHEY PRODUCTS USING MEMBRANE TECHNOLOGY

Thomas E. Petka and Andrew P. Mahon

INTRODUCTION

Many factors have contributed to the commercial need to add value to whey products and the simultaneous development of process and technology to make this possible. A brief reflection on the pressures that the dairy industry has been subjected to over the last ten years reveals many of these factors.

TABLE I. Factors affecting development of value-added whey products

• Pressures on cheese margins
• Energy costs
• Variability of traditional whey markets
• Environment

Pressure on Cheese Margins

The ever decreasing margin between the cost of raw material and sale price of the end product has forced cheese maufacturers to continue the search to add value to all the components of milk.

Energy Costs

The rapid escalation in energy costs of the 1970's has caused cheese manufacturers to sharply focus attention on the necessity to recoup the full value of all the ingredients of milk, having made such a large investment to recover roughly 50% of its composition.

Traditional Markets for Whey Powder

The tremendous fluctuation and uncertain fortunes of the whey powder market, together with its extreme vulnerability to the availability of other sources of carbohydrate, has led manufacturers to seek out more secure and stable markets for their products.

Environment

Even without the commercial incentives to change, the ever increasing consciousness of the necessity to protect the environment has caused manufacturers to seek profitable outlets for all the ingredients of milk rather than contribute a potential pollutant.

Against this background, the following opportunities have presented themselves to the dairy industry.

TABLE II. Opportunities for value-added whey products

• Sophisticated protein ingredient market
• Advancements in UF and RO technologies

Market Sophistication

In recent years, we have seen the development of a highly sophisticated protein ingredient market where not only quality and exacting specifications, but also protein efficiency and energy value per unit volume are the order of the day. This market has opened up primarily in the convenience, health food, and dietary sector—the dairy industry is an obvious supplier.

Technology

Simultaneous with the development of market opportunities over the last ten years, we have also seen technological developments in the areas of ultrafiltration and reverse osmosis membranes that allow the whey industry to participate in these opportunities.

From the early days of cellulose acetate membranes, we have progressed through the second generation of polysulphone membranes and are now on the threshold of the "so called" third generation of membranes—the mineral based. These technological developments have brought membrane processing within the grasp of the commercial whey processor to a point where membrane plants can be treated almost as regular dairy equipment.

Plant

The main application of membrane technology within the whey industry encompasses two basic processes—RO and UF.

RO

The main contribution of RO is as an alternative to evaporation. It can also serve as a very economical means in increasing capacity with an existing evaporator. Recent technology that allows the attainment of high levels of solids with RO alone puts RO in the position of having the capability to produce a saleable liquid product.

RO has an important role to play in processing small volumes of whey at remote plants with limited services that heretofore could not justify the investment in a process to produce a saleable product.

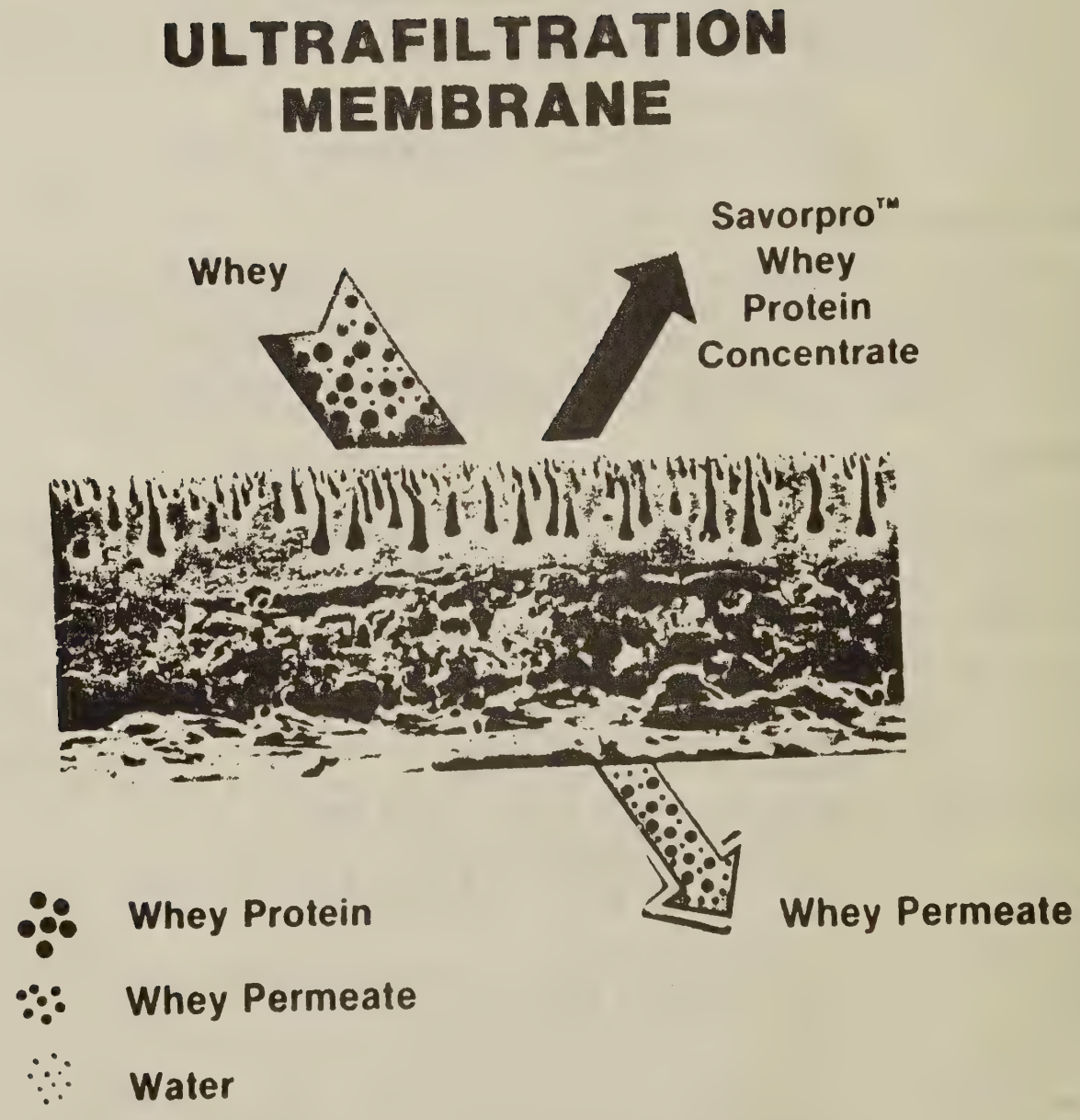

ULTRAFILTRATION MEMBRANE
Whey
Savorpro™ Whey Protein Concentrate
Whey Protein
Whey Permeate
Whey Permeate
Water

Figure 1.

REVERSE-OSMOSIS PROCESS

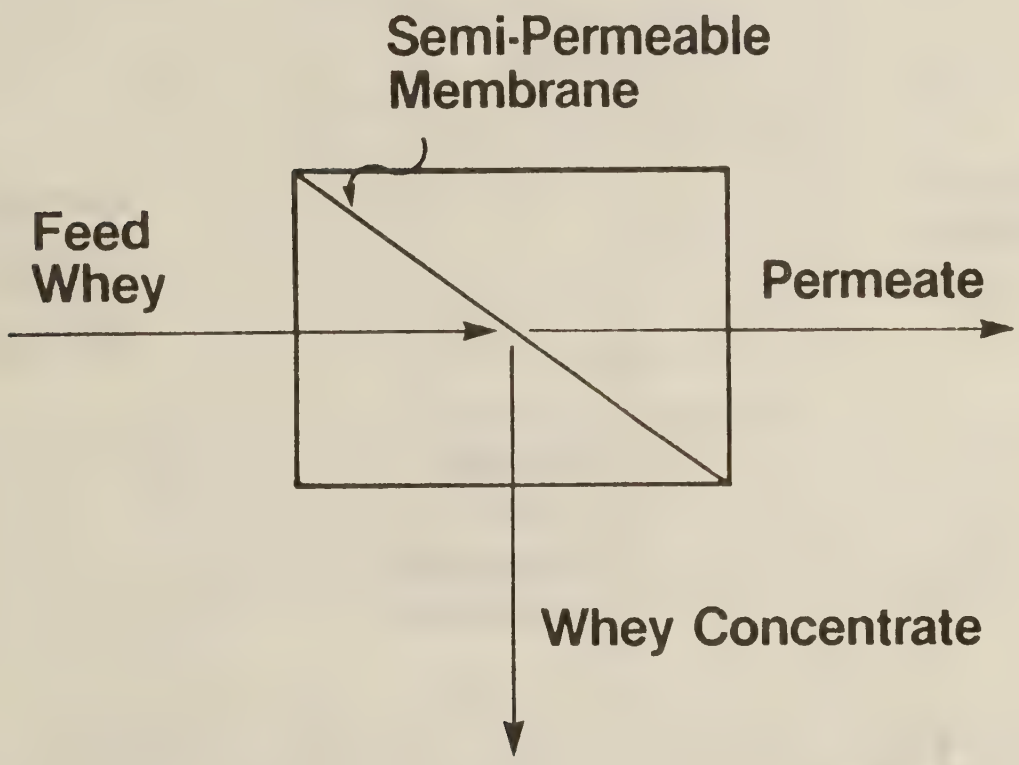


Figure 2.

UF

Ultrafiltration, however, has played a major role in opening up a wide variety of possibilities for whey and has led to the production of several additional new products.

UF plants are manufactured in a number of designs—spirals, hollow fiber, plate and frame, and tube, each of which has its own particular advantage depending on the application.

The main application of UF is for the separation of protein from lactose in whey; however, whey protein products are continually being developed and further development of membrane technology may lead to processes that will allow the fractionation of the individual proteins.

The basic process for producing ultrafiltrated whey is shown in Figures 4 and 5.

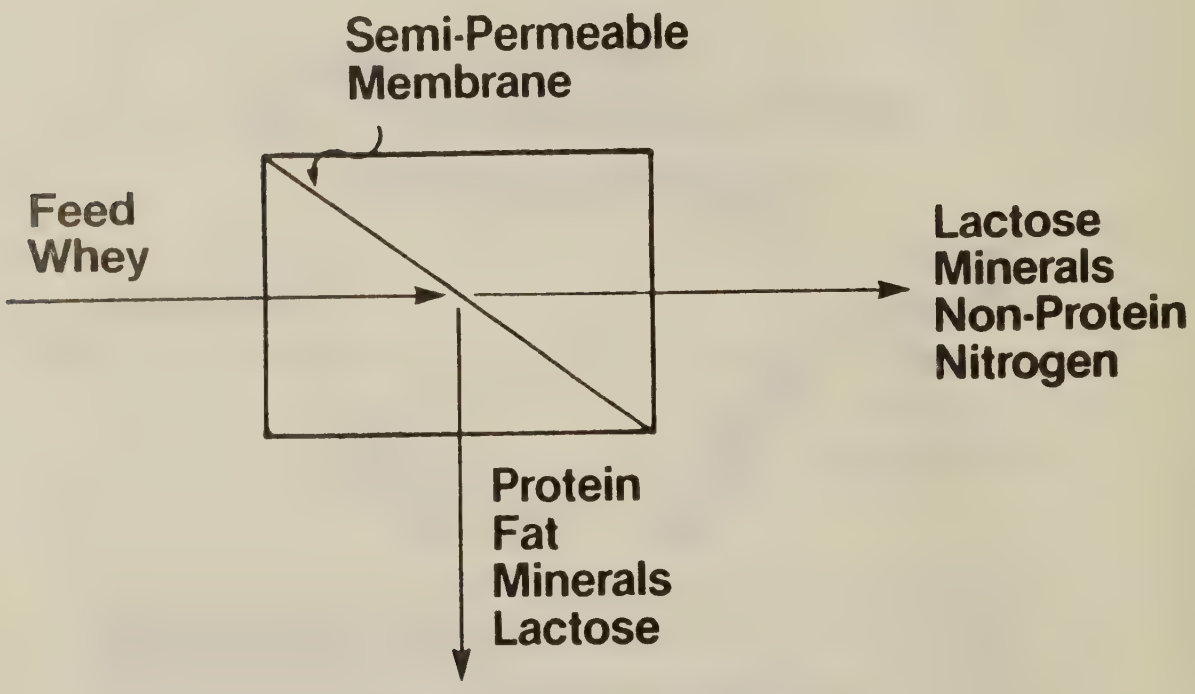


Figure 3.

The main focus of attention with regard to UF has been on the production of high value proteins; however, it would not be possible to install a UF plant for WPC without considering how the permeate/lactose was to be processed. A number of viable possibilities are available, the added value varying depending on location, proximity of local markets, local economics, and market demand.

Express has successfully exploited alcohol and dimineralized permeate and although methane was not considered for straight permeate, a plant has been installed to digest the spent wash from the alcohol process.

Flexibility

Any one of these processes can be used in its own right, or in combination with each other. A certain amount of merit exists in installing a flexible system that can adjust to changing demand.

One of the major current developments in membrane processing as it relates to whey products is the UF of milk for cheesemaking. Several cheese types are

TABLE III. Possible value-added opportunities for whey permeate

- Alcohol
- Lactose
- Demineralized permeate
- Glucose Galactose
- Methane
- Dried permeate

being produced in Europe using 4-6 times concentration of milk, in which a major part of the whey proteins are incorporated into the cheese, giving significant yield improvements. The result is that permeate is produced instead of whey, and the added value must now take into account the whey proteins as cheese, together with the value of the permeate. A further possibility is to produce a WPC that is capable of being incorporated into the cheesemaking process.

Now that I've reviewed the basic processing of value-added whey products, I will turn the program over to Tom Petka. He will continue the presentation by discussing commercial application and market opportunities for whey products produced by means of membrane technology.

Commercial Application and Market Opportunity for Value-Added Whey Products

As Andy noted, there is increasing demand by the food and pharmaceutical industries for high quality protein ingredients having specific functional properties and conforming to exacting specifications—both physical and chemical. Whey proteins are no exception.

TABLE IV. Whey protein concentrate and whey permeate

- Products of membrane technology
- Recognized and defined category of ingredients in the U.S.

Membrane technology has indeed been the primary factor in the development of value-added, functional whey products, namely whey protein concentrates and

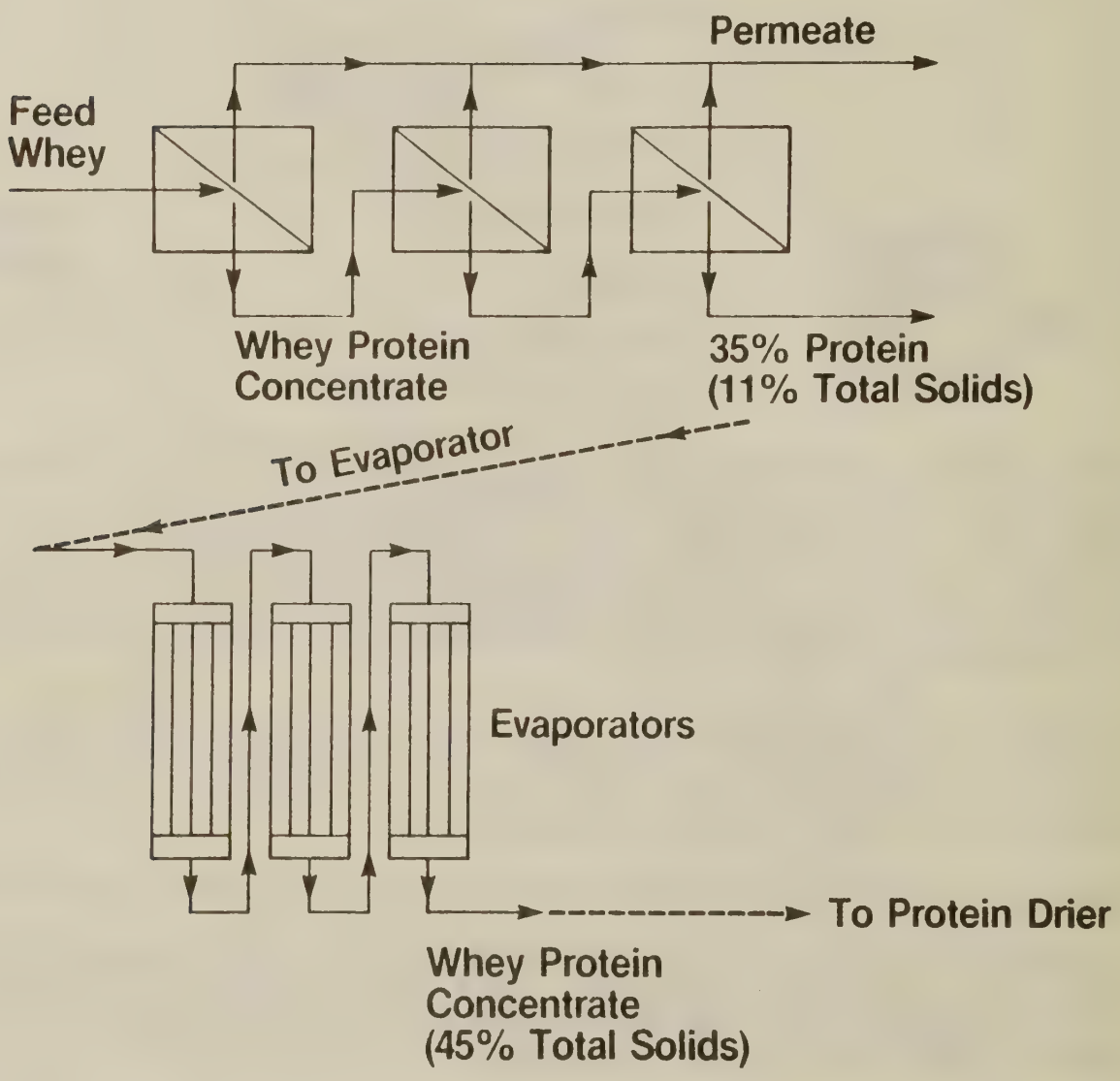


Figure 4.

whey permeates, which satisfy many of the food formulator's needs. Whey protein concentrates have been in commercial production for approximately 15 years; and in this time, have evolved into a recognized and well defined category of consistent quality protein ingredients.

TABLE V. Typical analysis "first generation" WPC

	WPC 35%	WPC 50%	WPC 75%
Protein	35.0	50.0	75.0
Ash	7.0	6.0	3.0
Carbohydrate (by dif.)	54.0	35.0	5.0
Moisture	4.5	4.0	4.0

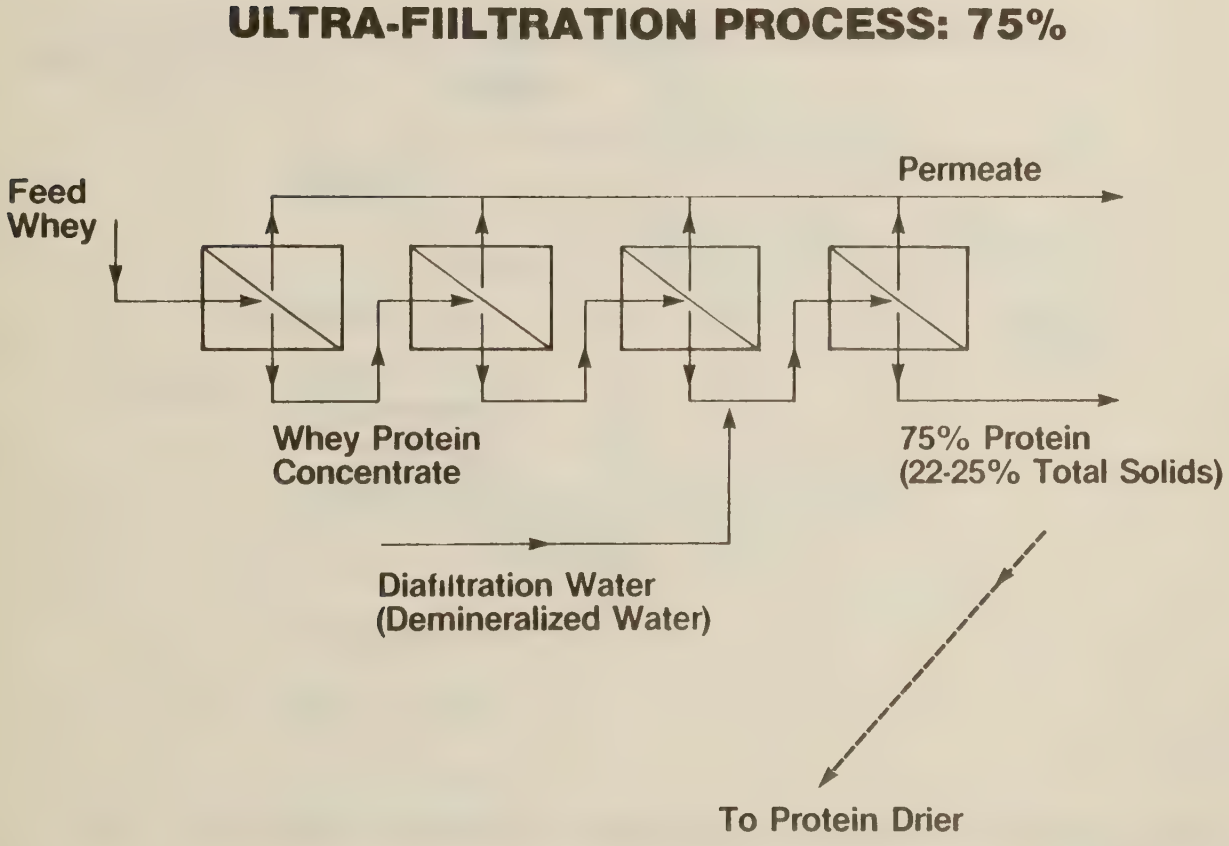


Figure 5.

Those whey protein concentrates processed strictly by the ultrafiltration process described by Andy, can be categorized as the first generation of whey

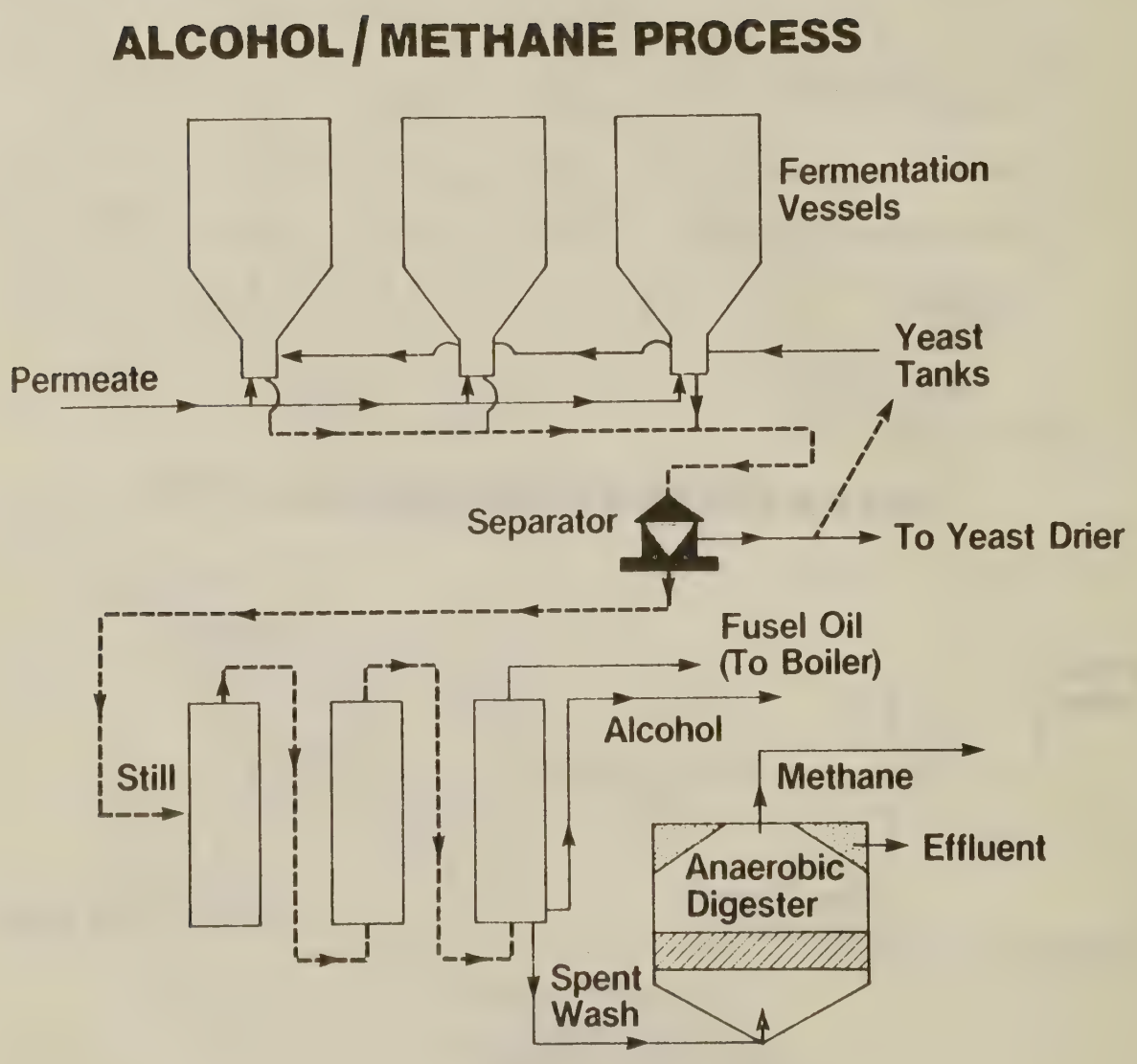


Figure 6.

protein concentrates and represent a major advancement in adding value to whey solids.

These WPC's range in protein content from 35% to 75%. While we may now take these products for granted, we should recognize that these WPC's are largely the result of progress in process development and membrane technology during the past decade.

Products on the lower end of the range are used as economical milk solids replacers, in processed cheese, ice cream, and confectionery and bakery

applications, while the higher protein products have application in more proprietary convenience products, protein fortified beverages, pasta, health foods, special dietary supplements, and as egg and/or milk solids replacers in bakery products and salad dressings.

These varied applications take advantage of the various physical and functional properties inherent to whey protein concentrates listed below:

TABLE VI. Current Applications for WPC

Low protein (less than 50%)	High protein (greater than 50%)
• Processed cheese	• Proprietary convenience products
• Frozen desserts	• Protein fortified pasta
• Confectionery products	• Protein fortified beverages
• Bakery products	• Health foods
	• Nutritional supplements
	• Egg/milk solids replacement in bakery products and dressings

TABLE VII. Physical and functional properties of WPC

- Excellent water solubility
- Bland flavor
- Low viscosity
- Thermal gelation and water binding
- Acid stability
- Excellent nutritional profile (her PER)

With the increasing marketing acceptance and use of whey protein concentrates, food scientists are now requiring modifications of the first generation WPC's. In some cases, these modifications can be accomplished by the adjustment and/or manipulation of certain process parameters, such as level of protein denaturation, pH, ash, and minerals, using established membrane and ultrafiltration technology.

Now that WPC has achieved the status of a bona fide protein ingredient, and highly sophisticated membrane (process) technology is available, it is appropriate that we look to the next generations of WPC which will provide more proprietary and specific functional properties. These products will add yet further value to whey and will be in response to identified marketing needs. These value-added whey products, which are in varying stages of commercial development, will utilize the most recent developments in membrane technology—frequently in combination with other processes such as chemical modification, enzymatic modification, and the related fractionation techniques of electrodialysis and ion exchange.

TABLE VIII. New generation value-added WPC

- Modified functionality
- Specific end use application
- Involve membrane technology in combination with:
  - (a) Chemical modification
  - (b) Enzymatic modification
  - (c) Electrodialysis
  - (d) Ion exchange

Specific examples of these marketing opportunities for value-added WPC's follow.

I will briefly review each of these potential WPC's starting with:

Cold Water Dispersible

High protein whey protein concentrates, like many proteinaceous ingredients, have poor cold water dispersibility properties. Instantized WPC's now provide a concentrated protein source ideal for use in powdered food and pharmaceutical products, which must be rapidly dispersible in cold milk or water before consumption.

The next type of value-added WPC is that of:

TABLE IX. New generation value-added WPC

• Water dispersible WPC
• High gel strength WPC
• Low lactose WPC
• Low gel temperature WPC
• Protein fractionation

TABLE X. High gel strength WPC

	Mean gel strength
WPC 75	254
High gel WPC 75	557

High Gel Strength

While WPC's have certain gelling properties, these properties are deficient in applications where the WPC will be an integral part of the gel structure. Such applications include meat analogs, processed meats, fortified pasta, quiche, and other egg applications. Special treatments of whey allow the opportunity to produce WPC's with increased gelling strength. On this slide, the mean gel strengths of a specially processed, high gel WPC versus a regular WPC 75 illustrates the improvements in gel strength that can be attained.

Another value-added product is:

TABLE XI. Low lactose WPC

• Less than 0.5% lactose

Low lactose WPC

The lactose content of whey proteins varies depending on the degree of ultrafiltration and, in many applications, presents no problems. However, there are certain applications where reduced levels of lactose are desired. Examples include special dietary products where lactose intolerance is a concern, or frozen desserts where lactose crystallization can be a detriment to the shelf life of the product. Advancements in chemical and enzymatic hydrolysis, in combination with membrane technology, now provide WPC with less than 0.5% lactose. Of course, intermediate ranges of lactose hydrolysis are also possible.

Yet another opportunity is:

TABLE XII. Low gel temperature WPC

• Gelation temperature less than 72°C

Low gel temperature WPC

Whey protein possesses certain physical properties that are similar to egg albumin, and there is continuing interest in the food and pharmaceutical industries to utilize WPC as a partial to complete replacer for albumin. However, for special bakery and dessert type applications, it is desirable to lower the gelling temperature of WPC from 72°C. Here again, process manipulation can alter these properties, resulting in value-added, proprietary whey protein concentrates.

The final value-added WPC opportunity is:

TABLE XIII. Protein fractionation

• Alpha lactalbumin
• Beta lactoglobulin
• Bovine serum albumin
• Immunoglobulins
• Lactoperoxidase

Protein Fractionation

As medical research continues to obtain a better understanding of the body's utilization of various whey protein fractions, there will be increasing demand to effectively and efficiently separate the various whey fractions such as alpha lactalbumin, beta lactoglobulin, bovine serum albumin, immunoglobulins, and lactoperoxidase. Potential applications for these fractions would be pharmaceutical products, as well as defined nutritional supplements. Advances in membrane technology, in combination with the related fractionation techniques of electrodialysis and ion exchange, are improving both the purity and efficiency of the fractionation process—most definitely value-added whey products.

At this time, I'd like to briefly touch on value-added whey permeate products. As Andy noted, permeate processing must be considered in any UF membrane process.

In his segment, Andy listed various opportunities for adding value to permeate including: (1) alcohol, (2) demineralized permeate, (3) lactose hydrolyzed permeate, (4) dry permeate, and (5) lactose.

In the U.S., the alcohol produced from whey permeate is directed primarily to industrial applications; however, in Europe, laws and regulations make its use permissible in food and liquor products.

TABLE XIV. Value-added whey permeate products

- Alcohol
- Demineralized permeate
- Lactose hydrolyzed whey permeate
- Dried permeate
  - (a) Whey/COH replacer
  - (b) Humectant
- Lactitol

Demineralized permeate is positioned as a "basic lactose" source. The controlled levels of specific minerals and nonprotein nitrogen (NPN) are indeed desirable in defined nutritional applications.

Lactose hydrolyzed whey permeate has been covered in detail, and I will therefore not dwell further on this topic.

Dried permeate, and modifications thereof, have accepted use in a variety of nonstandardized food products, largely as an economical whey or carbohydrate source. Included in these applications are bakery products, fanciful cheese products such as cheese sauces and dips, confectionery products, and batters and breadings. Admittedly, these are not a true value-added opportunity for whey permeate; however, they are commercial food applications for a product of the ultrafiltration process.

Another identified application for whey permeate and its derivatives is based on its humectant properties. These properties are attributed largely to the "derived protein" in whey permeate. Whey permeate provides comparable humectant and water activity reduction properties to 42DE corn syrup in specific intermediate moisture foods, such as semi-moist pet foods and icings. In Fig. 7, we are comparing the isotherms of semi-moist pet food systems where they permeate directly replaced corn syrup. As you can see, there is no change in the water activity at a given moisture level.

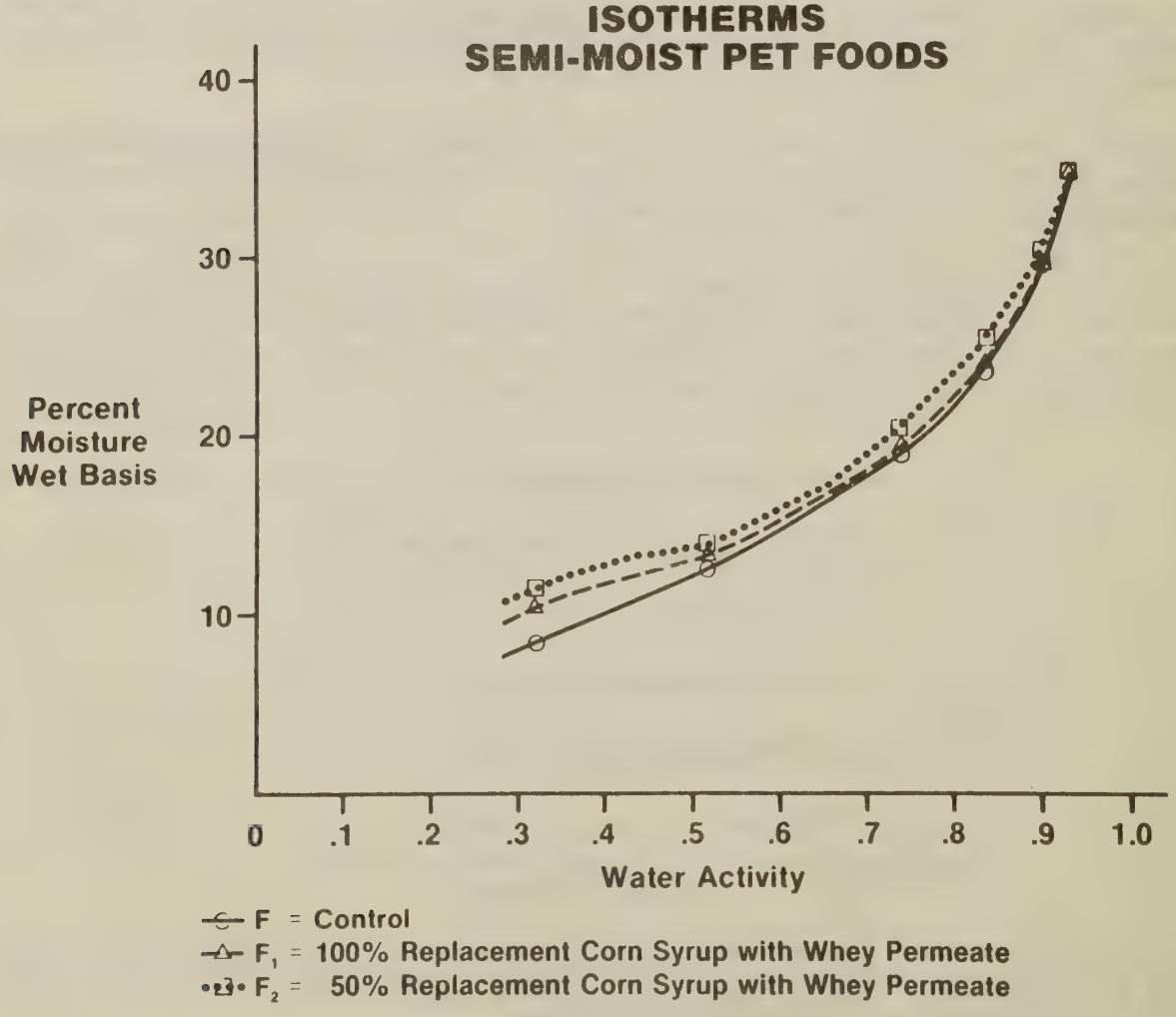


Figure 7.

TABLE XV. Lactitol

- Sugar alcohol prepared by hydrogenation of lactose
- Many virtues
- Many potential applications

Yet another value-added opportunity for whey permeate is the production of lactitol, a chemical modification of lactose. Lactitol is a sugar alcohol prepared by hydrogenation of lactose. Many virtues have been claimed for this compounds, from prevention of dental cavities to reduced caloric content. Petitions are now under study by the Food and Drug Administration for approval of lactitol in the U.S. Pending food approval, lactitol has potential use in special dietary foods including confectioneries, beverages, jams and jellies, and bakery products.

TABLE XVI. Future for value-added whey products using membrane technology

WPC

- Modified functionality for specific end use application

Whey permeate

- Continued research and developmental work required

In conclusion, membrane technology has been instrumental in the evolution of value-added whey products, namely whey protein concentrates, whey permeate, and derivatives thereof. Whey protein concentrate is now a recognized protein ingredient in the food and pharmaceutical industries. Future developments will involve modifying the functional properties of WPC for specific end use application, utilizing advancements in membrane technology and other processing techniques. Methods to handle and process whey permeate have advanced and it, too, has many established usages. However, additional research is required to develop new value-added opportunities for whey permeate in food rather than industrial applications.

HEAT RECOVERY SYSTEMS FOR SPRAY DRIERS

George P. Duensing
Marriott Walker Corporation
Birmingham, MI

INTRODUCTION

Heat recovery is a form of energy conservation. The cost of energy is increasing much more rapidly than most other costs of food production. Therefore, energy conservation is more important now that it has ever been in the past. While the subject of this talk is the recovery of waste heat from spray drier exhaust air, we must also consider other energy conservation methods in the total process of spray drying products at lower costs.

For an overview of the energy used in concentrating skim milk to finished dry product, please direct your attention to Appendix "A". It can be shown mathematically that condensing skim milk from 8.7% to 42% total solids removes 87% of the water while drying from 42% to 97% total solids removes 13% of the water. The total energy used for water removal gradually decreases as the evaporator efficiency increases. In all cases, observe that the drier requires considerably more energy than the evaporator while accomplishing only 13% of the total work.

When considering the most efficient evaporators available today, we find that 95% of the total energy required for water removal is used by the drier. Two methods available to substantially reduce the total energy requirements are condensing to higher solids with a finishing evaporator and recovering waste heat from the drier exhaust air.

The shaded segment of the circle charts represents an average expected savings of total drying energy when heat recovery is properly incorporated. Note that the recoverable heat considerably exceeds the energy requirements of the evaporator. Thus, we must look at heat recovery as an alternate, low cost energy source which can be very cost effective with properly applied equipment.

TYPES OF DRIER HEAT RECOVERY SYSTEMS

Heat Pipe Systems

Heat pipe coils are made up of individual sealed finned pipes which extend into both the hot and cold air streams on an incline, the lower end being in the hot air stream. Heat from the exhaust air causes a refrigerant liquid inside the pipe to vaporize and to migrate to the cold air side where it is condensed, giving up heat to the incoming air. The liquid runs back to the hot end to complete the cycle. This application has been used in a number of heat recovery systems such as economizers for boiler flue gas and has been used in our industry successfully on some drier installations.

Fin spacing is dictated by the drier dust collection method and the exhaust air should flow downward through the coils so that sprays can be installed

APPENDIX A

ENERGY REQUIREMENTS TO EVAPORATE A DRY PRODUCT

Gains by Drier Exhaust Air Heat Recovery

In evaporating 8.7% solids skim milk to 42% solids, and then drying to remove 3% moisture, it can be shown mathematically that of the water removed, 13% is by the drier.

In recent years, great gains have been made in evaporator efficiency while driers have remained at their traditional inefficiency of requiring up to 3.2 pounds of steam to evaporate a pound of water. The cost of drying has now become substantially more expensive than the cost of evaporating. The hot exhaust air of the drier, now rejected to atmosphere, becomes a valuable resource to reduce total air heating costs. The circle charts below show the amount of heat recovery that might be expected, and its importance with regard to total energy requirements for water removal. The pie section marked "F.E." represents that portion of the total drier energy saved by increasing the skim concentrate solids to 50% in a finishing effect.

TOTAL ENERGY CHARTS

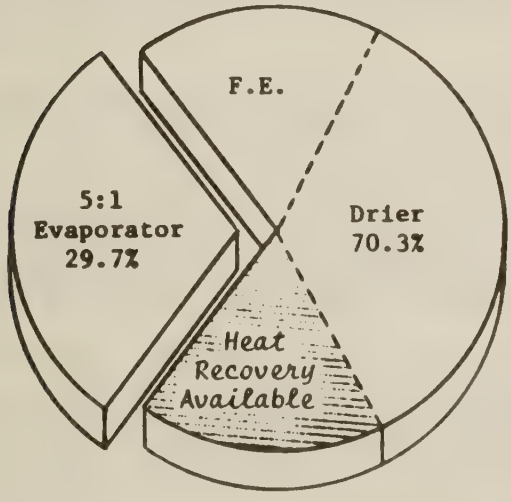


Chart #1 -- 5:1 Evaporator

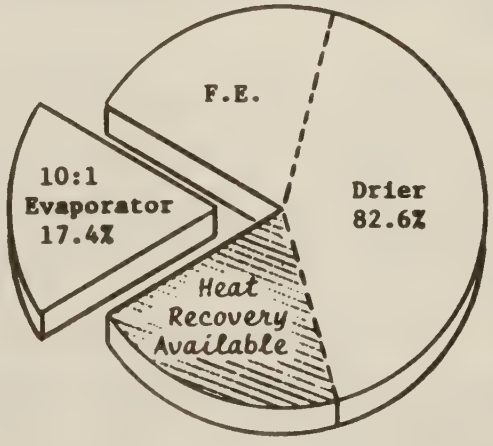


Chart #2 -- 10:1 Evaporator

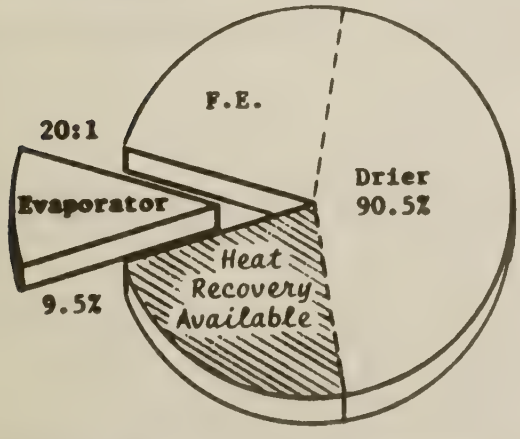


Chart #3 -- 20:1 Evaporator

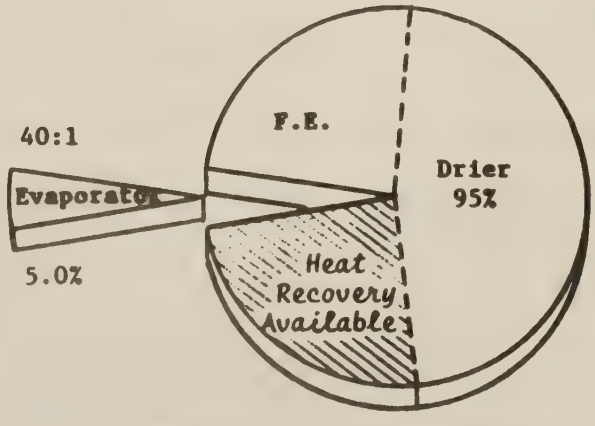


Chart #4 -- 40:1 Evaporator

above the coils for effective cleaning. One manufacturer of these coils has advised us that they install four fins per inch of pipe on the exhaust air side of the cyclonic collection driers, eight fins per inch on baghouse collection driers, and up to fourteen fins per inch on the inlet air side. Various materials of construction are available, although we feel that stainless steel is the most desirable from the standpoint of longevity and cleanability of the coils.

While the heat pipe design is unique, it is similar in operation to an air-to-liquid-to-air system. The difference here is that the energy to transfer the fluid from one end of the finned pipe to the other is the difference in density between the vapor state and liquid state of the refrigerant. The units are self-contained and there is no auxiliary equipment such as pumps and piping to operate and maintain.

Air-to-Air Systems

A number of different air-to-air heat exchangers have been designed through the years. There have been tubular types, corrugated plates, packed beds, etc. These designs were used as recuperators on boilers, furnaces, and gas turbines in generating plants. Two types of air-to-air heat exchangers are generally used on spray driers. One is a folded plate type and the other is tubular.

The plate type consists of folded aluminum or stainless steel plates separating the inlet and exhaust air streams, with these plates being set in a sealant material at the top and bottom of the plates. The inlet air flows across and down one side of the plates while the exhaust air flows across the up the other side. Spray devices set into the exhaust air side move back and forth spraying cleaning solution on the plates. We believe that such units should be fabricated of stainless steel to prevent corrosion, provide long life, and assure good cleaning and sanitation.

Tubular type air-to-air heat recovery systems are manufactured by a number of different companies and are available in both glass and stainless steel materials.

Generally speaking, air-to-air units are quite large, require extensive ductwork systems and therefore should be designed into the drier systems at their inception so as to minimize ductwork cost.

Air-to-Liquid-to-Air Systems

Air-to-liquid-to-air systems utilize propylene glycol solutions pumped between coils installed in the exhaust and inlet air streams. Usually these systems are easier to retrofit on existing driers because they require less extensive ductwork revisions in the inlet area. However, they do require an exhaust housing for the coils designed to distribute the air evenly across the coils, provide sufficient coils to maximize heat transfer and permit good cleanability. We prefer to design the systems with face and bypass dampers so that the drier can continue to run with the exhaust air bypassing the system if a problem should develop in the coils. While the air-to-liquid-to-air

system lends itself very nicely to retrofitting, it may also be used on new drier installations where space is limited.

DESIGN AND CONSTRUCTION

Efficiency

The heat recovery unit manufacturers generally specify efficiency as the ratio of the supply air temperature rise ($S_2 - S_1$) through the heat recovery unit to the temperature difference between the exhaust and supply air temperatures to the heat recovery unit ($EX_1 - S_1$):

$$\text{Efficiency} = \frac{S_2 - S_1}{EX_1 - S_1} \times 100$$

This is accurate only until moisture is condensed from the exhaust air stream. Beyond this point, the true measure of effectiveness is in how much heat is transferred to the supply air stream. An absolute value can be determined only if the actual supply air flow rate is known. Since this is difficult to determine, we compare the temperature rise of the supply air ($S_2 - S_1$) through the heat recovery unit to the total temperature rise of the supply air ($S_3 - S_1$) to the drier:

$$\text{H.R. effectiveness} = \% \text{ fuel saved} = \frac{S_2 - S_1}{S_3 - S_1} \times 100$$

Theoretically, air-to-air systems are more efficient than air-liquid-air systems. In air-to-air systems, one heat transfer takes place. In air-liquid-air systems, two heat transfers take place.

In researching information for this paper, we have compared operating data between a folded plate air-to-air system and a pumped propylene glycol air-liquid-air system which appears to confirm the efficiency difference. Our data indicates that the air-to-air system is about 20% more efficient than the air-liquid-air system, but this efficiency is achieved at a considerably greater first cost.

We have not investigated all types of heat recovery systems. Although heat pipes appear to have very good thermal efficiency, we have not yet located stainless steel units at reasonable costs. There may also be systems of other designs worthy of consideration. We, therefore, must leave to you, the prospective owner of the equipment, the evaluation of the anticipated heat recovery effectiveness of individual proposals against their design to fit given circumstances and first costs.

Cross-Contamination

The potential for cross-contamination of the filtered supply air by dusty exhaust air is greater in the air-to-air heat recovery systems than it is in air-liquid-air systems. This could occur through corrosion or breakage of the separating material. When designing an air-to-air system, careful

consideration should be given to the air pressure difference between the supply and exhaust air streams so that any breach in the separating wall would permit supply air to flow into the exhaust air rather than the other way.

Heat pipe systems could cross-contaminate in the same manner as the air-to-air system. Additionally, individual refrigerants should be questioned with regard to their contamination potential, should a tube develop a leak.

Air-liquid-air systems cannot contaminate the supply air stream, even if a leak in a coil were to develop. We use a propylene glycol and water mixture as the heat transfer fluid. The propylene glycol functions as an antifreeze and is Generally Recognized as Safe by the F.D.A.

Heat Recovery System Design vs. Drier Dust Collection Systems

Three types of dust collection systems are generally installed on driers in this country. These are wet scrubbers, cyclonic collectors, and baghouses.

Where wet scrubbers are used, heat recovery systems would necessarily have to be installed between the drier cyclones and the wet scrubber, which would then expose the heat recovery system to the relatively high dust loadings that discharge from cyclonic collectors. Heat recovery systems are of little benefit if installed downstream of a wet scrubber, due to loss of exhaust air temperature in the scrubber.

Where cyclonic collectors are used, the dust loadings can be sufficient to cause problems in any heat recovery system of the fin and tube type, unless the fins are generously spaced and the air flow arranged through the coils so that a C.I.P system can clean the coils regularly. We prefer that the exhaust air flow downward through both air-to-air and air-liquid-air heat recovery units so that spray cleaning is done in the same direction as the air flow.

We prefer to install baghouses upstream of the heat recovery units, either integrally with the drier or retrofitted. This provides the maximum dust collection efficiency and at the same time prevents a high dust loading to the heat recovery system. We also use dust detection devices to alert the operating personnel of problems such as broken bags. Even with the use of bags, there is sufficient fine dust in the exhaust air to stick to the wet rows of coils or tubes. Therefore, cleaning the exhaust air side of a heat recovery system is absolutely necessary and a C.I.P. system should be designed as an integral part of any heat recovery system.

Materials of Construction

Materials of construction do not generally play a big part in the heat transfer phenomenon of heat recovery units, other than dictating the square footage of heat transfer surfaces. The conductivity of air is so low as compared to the material used in the heat transfer surface that other factors are much more important in designing these systems, such as air velocity, entrance and exit ductwork, and cleaning methods.

Since heat is transferred from one air stream to another, the conductivity of the surface film of air on the coils provides the greatest resistance to heat transfer. Therefore, the material used to separate the two air streams is of relatively small consequence in overall heat transfer. It is because of this that materials such as glass, ceramics, and stainless steel can be used readily for this purpose. The material selected should be durable, corrosion resistant, smooth, and easily cleaned.

We have utilized several different materials in the construction of the coils for the air-liquid-air systems and have concluded that the use of stainless steel coils with plate fins in the dusty air stream is the most desirable. These are readily cleanable and will provide a long life such as should be expected of a spray drier in general.

Cleanability

There have been several instances in our industry where heat recovery systems have not cleaned well. One installation we saw had the coils installed in a vertical position so that the air moved horizontally. Under these circumstances, sprays placed in the ductwork would not adequately penetrate the coils and the coils finally plugged. We also know of one system installed without cleaning which plugged and had to be removed.

While fin spacing is an important part of the design for coil cleanability, we also believe that cleaning the coils frequently is just as important for maintaining the system in good working condition.

The heat transfer surface, whether coils, plates, or tubes, must be designed and oriented so as to minimize condensate retention while operating and properly distribute and drain the C.I.P. solutions during cleaning.

A C.I.P. system should be properly designed into the heat recovery system so as to permit chemical solutions to clean any product from the heat transfer surfaces. This dictates the use of stainless steel for the housings and for the C.I.P. supply and return systems. A source of heat such as steam injection is desirable to heat the cleaning solution.

Face and Bypass Dampers

Generally, we recommend the installation of face and bypass dampers on the heat recovery systems so as to allow bypassing the air stream around the heat recovery system should it become plugged, require cleaning during an extended run, or require repairs. Most important is to provide flexibility for the drier operation.

As in any air handling system, care must be exercised in the design of ductwork, dampers, elbows, and transitions, etc., so as to distribute the air uniformly through the heat recovery unit and thereby recover the maximum heat available from a given system.

Retrofitting Heat Recovery Systems To Existing Driers

There are many facets to be considered when selecting the type of heat recovery system to be retrofitted to an existing drier. Among these are cyclonic versus bag dust collection, type of product being dried, space available for the heat recovery system, overall design of the heat recovery system in relation to the drier and building, and existing fan capabilities.

Typically, air-to-liquid-to-air systems require considerably less building space than do the air-to-air systems. We have considered some very large air-to-air systems for installation on existing driers and have found them to be expensive as they required substantial structural support and major duct-work modifications and extensions. Many existing driers have limited building space and therefore lend themselves very nicely to the air-liquid-air systems.

Air-liquid-air systems usually have a lower first cost than do air-to-air systems. With all facets studied, the final decision as to type of system must include consideration of return on investment.

Cost and Cost Recovery

The first cost of any system will depend upon the type of system (heat pipes, air-liquid-air, or air-to-air), the materials of construction and construction details, the available space for the system, and whether it is a retrofitted or new installation. The cost recovery time will depend upon the heat recovery effectiveness of the particular system with respect to its first cost. Most systems we have studied provided a simple payback of first cost in less than two years. Other suppliers have indicated similar payback periods.

CONCLUSIONS

Every drier should be considered for the potential heat recovery from the exhaust air. Tremendous energy savings can be realized by using this heat source.

While single stage driers, such as used for milk drying, offer a greater potential savings than do two stage driers, no drier should go without investigation. Even a small second stage drier, such as used for whey, could justifiably contribute to savings of fuel.

Heat recovery systems may be eligible for tax credits under many energy conservation incentive programs, as they are recuperating devices. Investment credits should also be realized.

In conclusion, we emphasize that you are losing money if you operate a spray drier without heat recovery. Stop that loss now. Reduce your costs. Save fuel with a heat recovery system.

24

FOULING AND CLEANING IN MEMBRANE PROCESSES

INVOLVED IN DAIRY APPLICATIONS//

Gerold Luss
N. B. Fuller Company

INTRODUCTION

The major application of membrane filtration in the dairy industry has, to date, been restricted to the processing of whey. Currently, however, it appears that other applications have been developed to the point where whey processing will no longer occupy the dominant position that it has had for the past ten years. However, the experience gained from the advances made in dealing with the fouling problems encountered in the processing of whey will doubtless carry over to these emerging application areas and both speed their successful introduction and permit their further development without the difficulties that were encountered in the early whey treatment membrane plants.

The MONARCH DIVISION of the H. B. FULLER COMPANY has been involved with the commercialization of membrane filtration equipment in the Dairy Industry by virtue of the fact that successful operation of membrane equipment depends upon daily cleaning to restore the units' operational capabilities. As suppliers of both detergents and cleaning expertise to our customers, we quickly became aware of the types of problems that could be encountered in this type of equipment and were able to assess the extent to which reproducible daily operation depended both on the development of a satisfactory cleaning regime and the provision of process improvements and/or changes in order to guarantee success.

Flux Measurement

At present, the primary measure of the success of a cleaning regime has been taken as the restoration of flux to the membrane unit. This has been measured primarily in two different ways in production scale units. The first is the restoration of water flux at the end of the cleaning cycle. In this method, water, used as a test fluid, is passed through the unit under set conditions of temperature and pressure and the amount of water which passes through the membrane is measured to determine whether cleaning has been successful. This method has several drawbacks among which are the daily variations in water temperature, the daily variations in water quality, the difficulty in controlling the pressure, variations in membrane integrity, and the inadequacies of flow meters. The second method, which has been used frequently, is a measurement of the initial product flux obtained upon returning the unit to service. This method is generally superior to water flux as a test method but suffers from the obvious drawback that it is not a predictive test but a confirmatory one. Another failing of this method lies in the variability of the product being introduced. The method which we have found to give the best results is the measurement of the total elapsed process time measured over a series of days runs. This method also lacks immediate predictive ability and cannot be used as a check on daily results but it does have the

ability to show long term trends in cleaning effectiveness and can also point out the need for extra cleaning cycles in a unit which has achieved some stability in operation.

Process Flux and the Origins of Fouling

The factors which affect process flux have been fairly well evaluated and have been identified as the following.

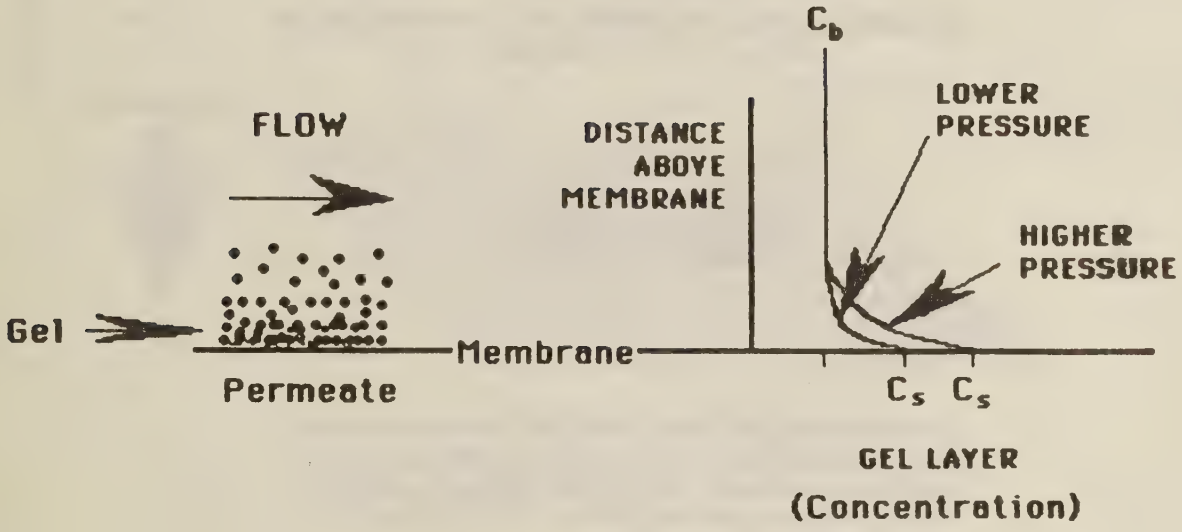
1. pH and mineral content of process stream
2. Temperature of the process stream
3. Extraneous fouling components in the feed stream such as fats, lipids, defoamers, fines, etc.
4. Microbiological state of the feed stream

We will briefly examine these factors and the effects that each of them has on process flux. We will also, in some cases, indicate the cleaning and/or process step that may be taken to combat their effects.

TABLE I. A comparison of reverse osmosis, ultrafiltration, and microfiltration

	Reverse osmosis	Ultrafiltration	Microfiltration
Size of solute retained	Molecular weights generally less than 500	Molecular weights generally over 1000	Suspended solids, insoluble oils, bacteria, yeasts, molds
Osmotic pressure of feed solutions	Important, can be over 1000 psi	Unimportant	Unimportant
Operating pressure	Greater than 100 psi and can range up to 2000 psi	10 to 100 psi	2 to 20 psi
Nature of membrane	Diffusive transport molecular screening	Screen filtration	Screen filtration, depth filtration
Chemical nature of membrane	Important in retention properties	Generally not important	Generally not important
Nature of fouling	Surface fouling	Surface fouling, internal fouling infrequently	Internal fouling

Concentration Polarization



C_b = The bulk concentration
C_s = The concentration next to membrane

As pressure increases flux through the membrane increases. This leads to a more concentrated polarization layer. When the concentration increases to the point where a gel is formed then flux no longer increases with pressure.

Figure 1.

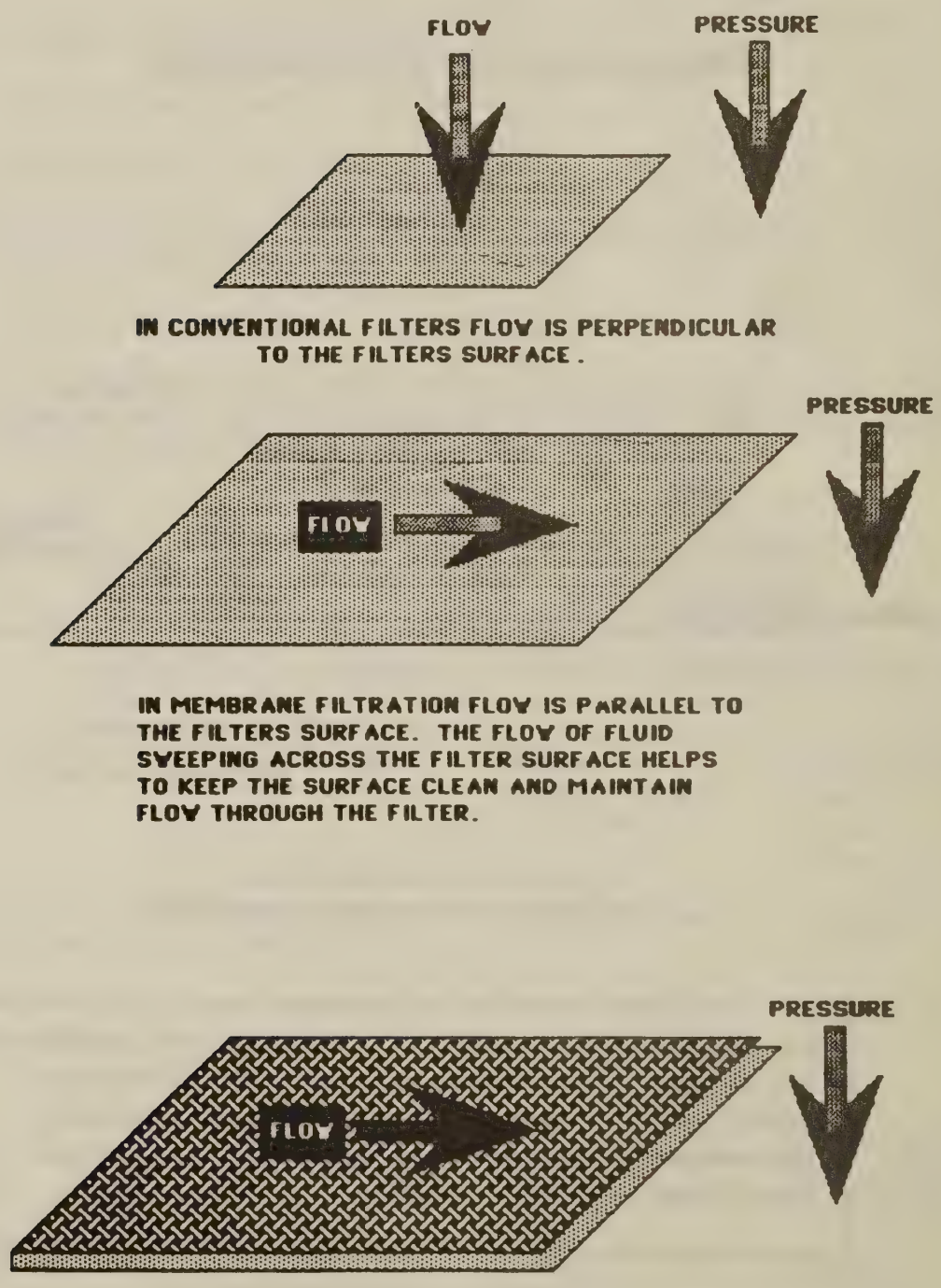
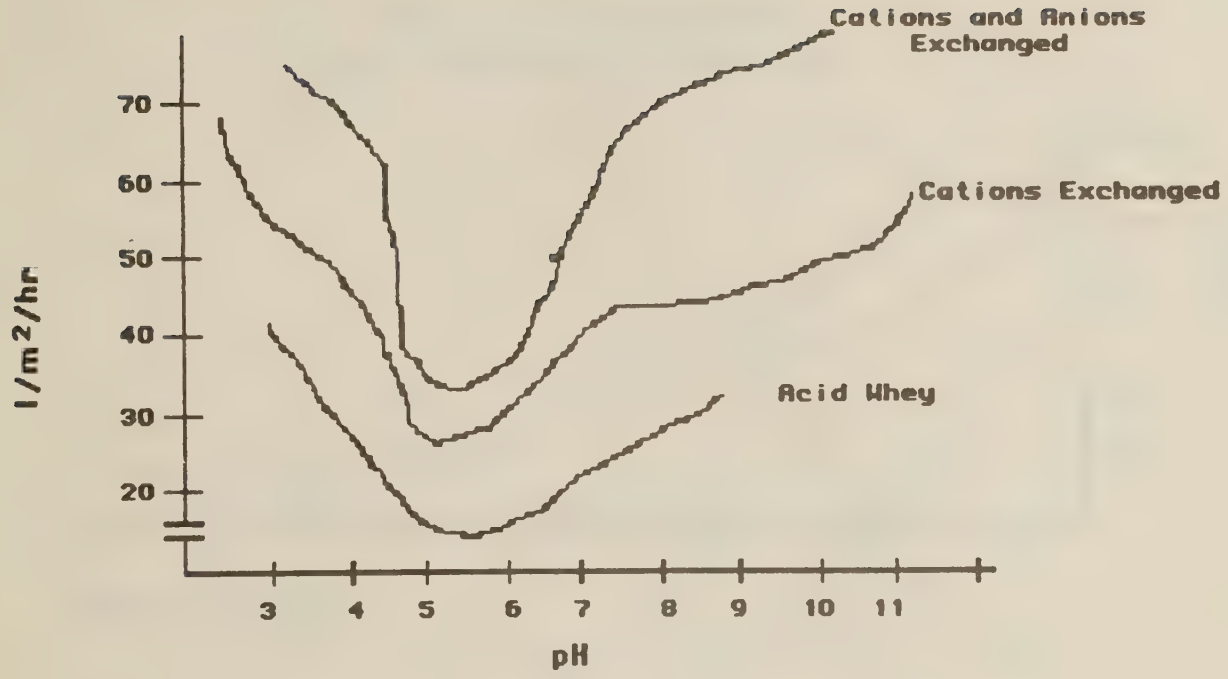

CROSSFLOW FILTRATION
FLOW
PRESSURE
IN CONVENTIONAL FILTERS FLOW IS PERPENDICULAR TO THE FILTERS SURFACE.
PRESSURE
FLOW
IN MEMBRANE FILTRATION FLOW IS PARALLEL TO THE FILTERS SURFACE. THE FLOW OF FLUID SWEEPING ACROSS THE FILTER SURFACE HELPS TO KEEP THE SURFACE CLEAN AND MAINTAIN FLOW THROUGH THE FILTER.
PRESSURE
FLOW
TO OBTAIN BETTER SWEEPING FROM THE FLOW SOME FILTERS ARE COVERED WITH A MESH THAT PROMOTES FLUID TURBULENCE.

Figure 2.

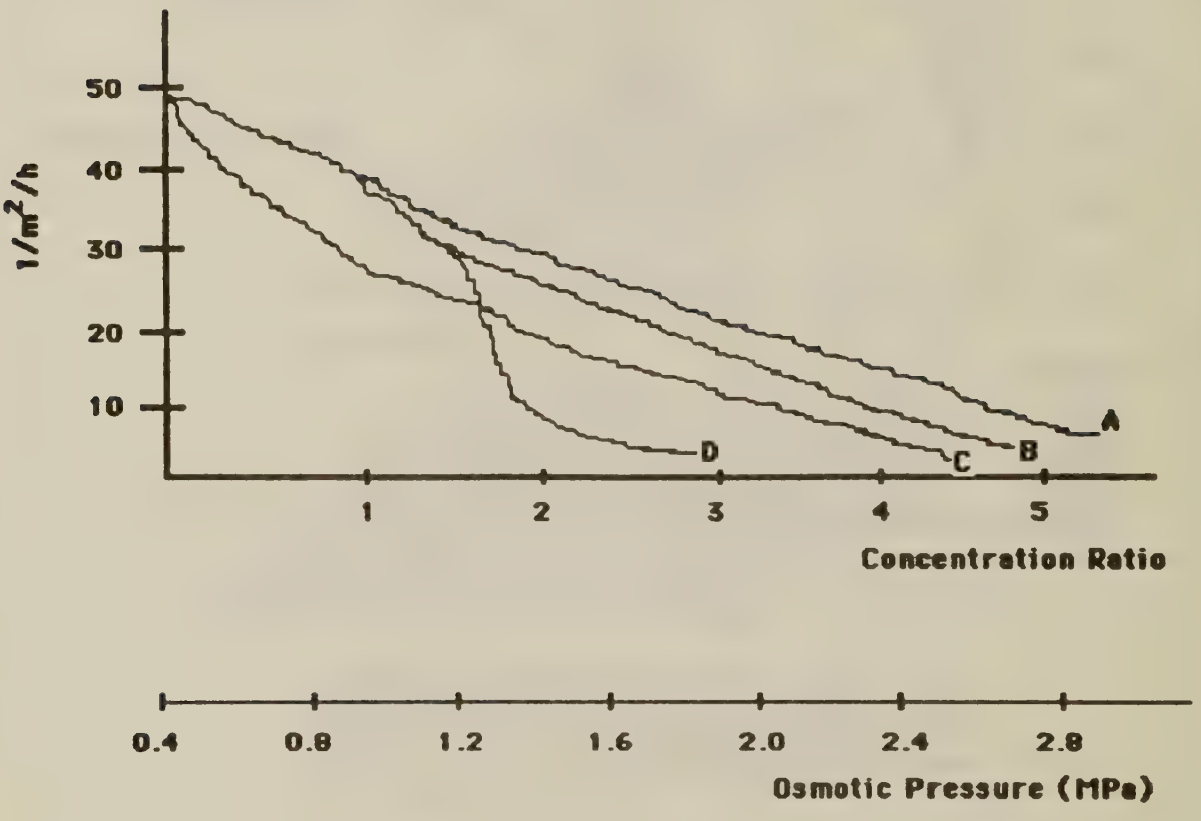


The effect of pH on UF flux for acid whey and whey that has been fully and partly demineralized.

Figure 3.

The fouling that is generally encountered while processing is usually initiated in the concentration polarization layer that is formed when processing in any crossflow membrane filtration unit. In Figure 1 the origin of the concentration polarization layer is shown. This layer leads to an increased concentration of membrane retained species at the membrane surface due to the passage of water and non-rejected species through the membrane. This concentration polarization layer is in the place in which mineral precipitation, microbial growth, and other fouling phenomena take place. To minimize fouling all membrane units today are operated on the crossflow principle (see Figure 2). This simply means that the process fluid is passed tangentially over the surface of the membrane in order to sweep as much of the fouling layer as possible away from the membrane surface and thus minimize fouling.

The pH of the incoming whey has a major effect on the performance of a membrane unit. In whey processing the pH serves as an indicator of the microbiological condition of the feed stream and it also controls protein and



RO CONCENTRATION OF GOUDA WHEY

A. Theoretical - Concentration Polarization Only

B. Whey at pH 6.0

C. Whey at pH 4.6

D. Whey at pH 6.6

Figure 4.

mineral solubility in the whey. In Figure 3 is a graph that shows the effect of pH on UF flux for various types of whey. In general, one expects to see effects of this type on flux in both RO and UF systems. The graph also points out the effect that mineral interactions with protein and pH have on

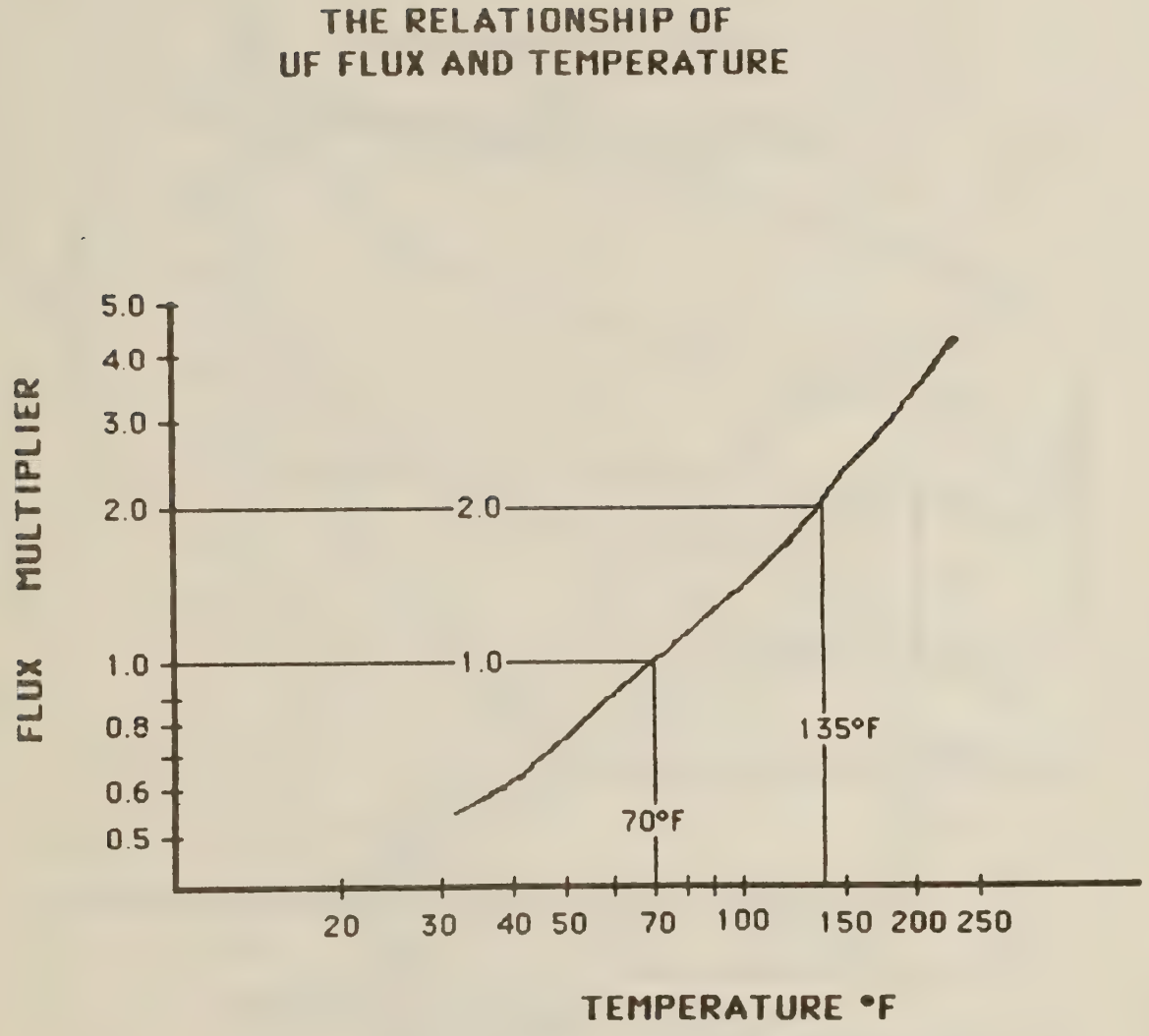


Figure 5.

the flux. In general, in all UF systems one expects to see an effect of this basic type. In RO (Figure 4) the situation is slightly different because the membrane is impermeable to calcium phosphate. This means that mineral solubility is strongly dependent on the interaction between the concentration factor and the pH.

The temperature also has a strong effect on UF flux as is shown in Figures 5 and 6. In Figure 5 we see that UF flux is strongly influenced by temperature when in concentration factor is the same. In Figure 6 we see that, as the protein concentration in a test solution increases, the fluxes at all tempera-

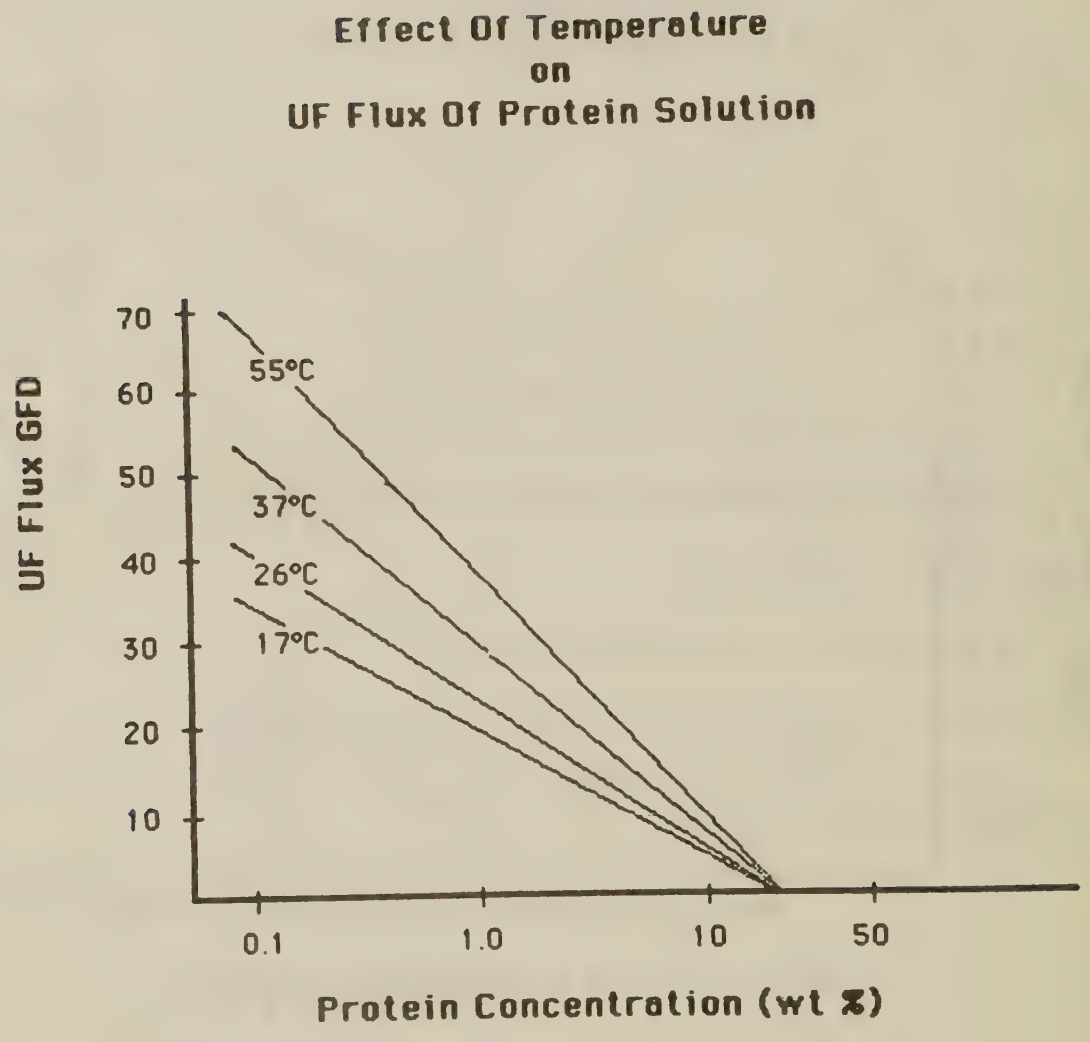
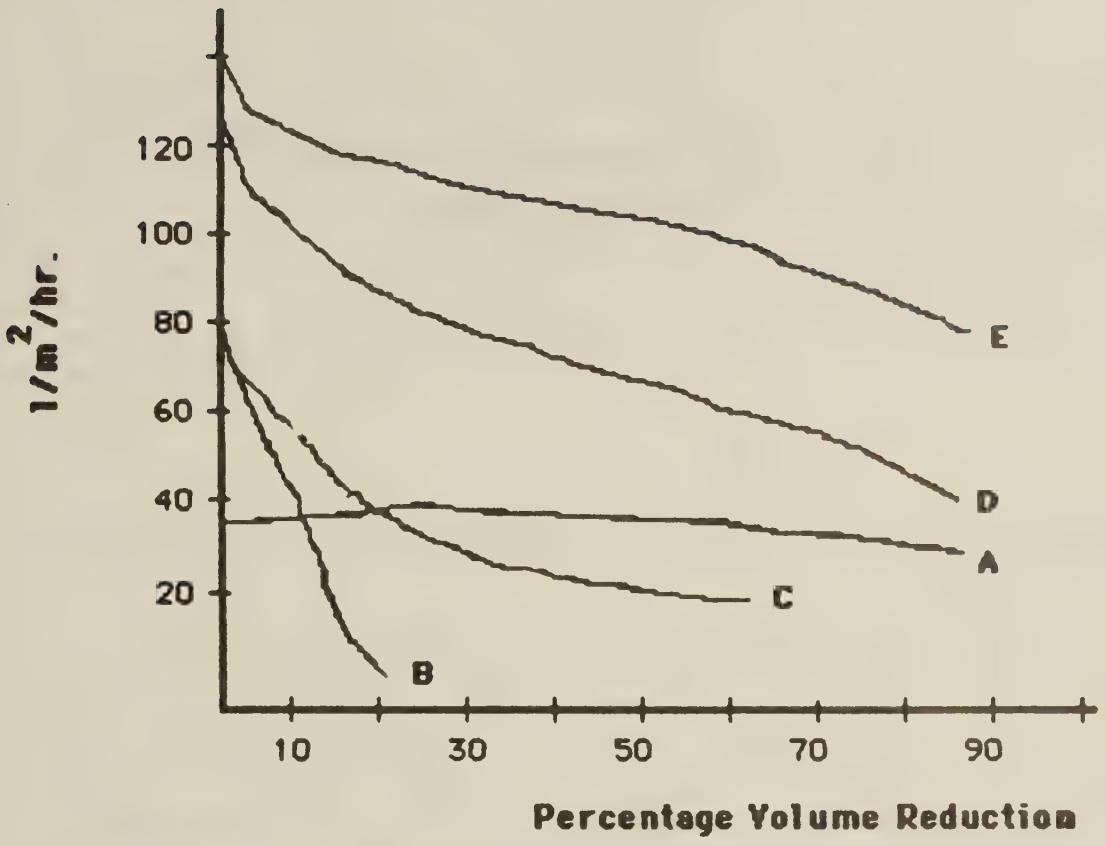


Figure 6.

tures converge. In general, other factors remaining constant one also expects to see the same types of phenomena in whey RO—i.e., higher fluxes at higher temperatures and a convergence of the flux values as the concentration factor increases. In Figure 7 we see that temperature history can also affect the observed fluxes. The two chief operating methods used currently in the industry are those designated by lines A and E. The advantage of the low temperature process is that both microbiological growth and mineral precipitation are minimized although this is done at some expense in flux. This is the principal method of operation for those systems which run on CA membranes



A. Hold 10° C - UF Temperature 10° C

B. Hold 10° C - UF Temperature 55° C

C. Hold 45° C - UF Temperature 55° C

D. Hold 55° C - UF Temperature 55° C

E. Hold 60° C - UF Temperature 50° C

High Temperature Holding Time
30 Minutes

Figure 7.

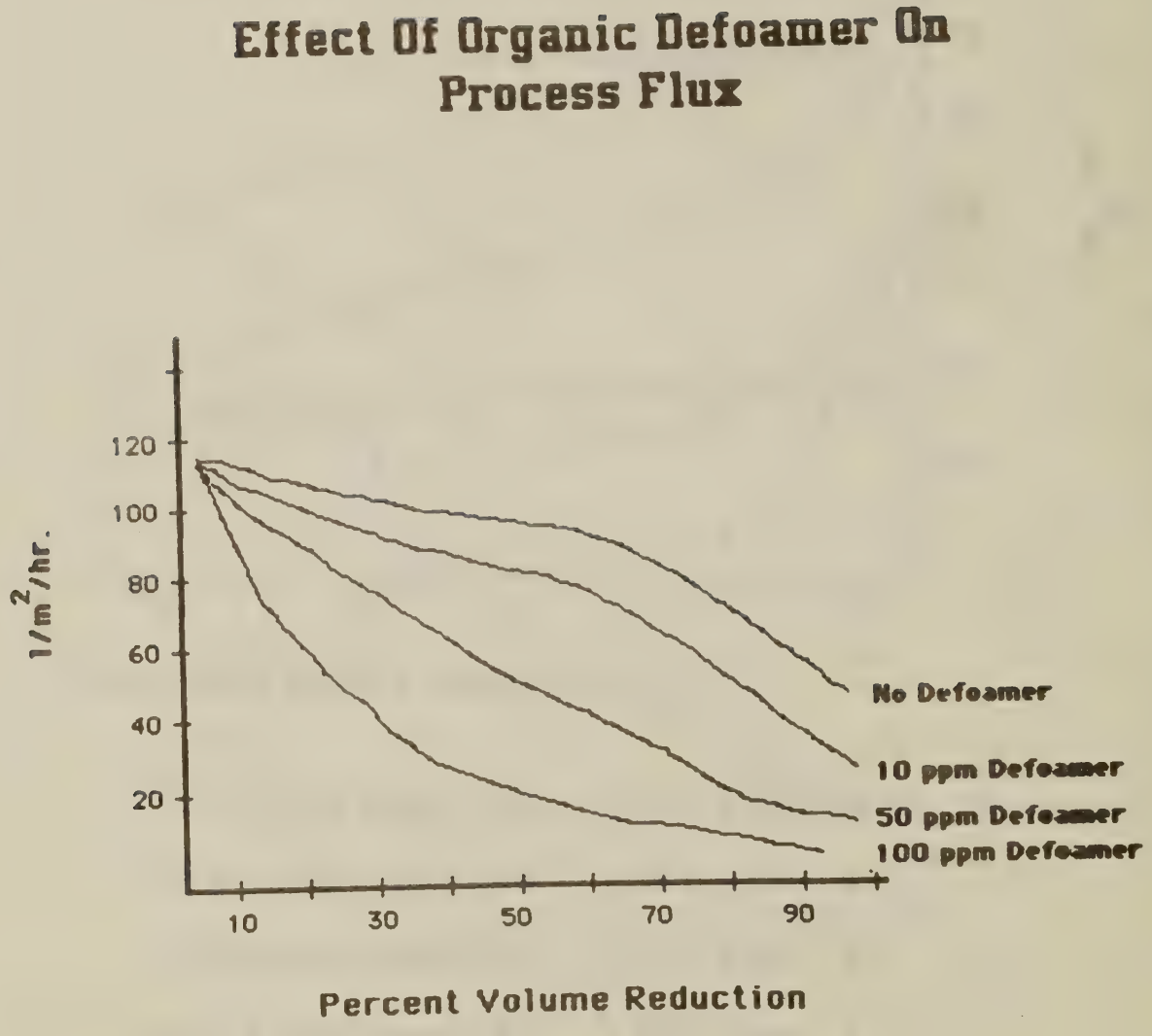


Figure 8.

today. The other method designed by E is generally used by systems which have polysulfone membranes.

The concentration of insoluble material in the feed stream can greatly affect the performance of a membrane unit. In Figure 8 we see the effect that an organic defoamer can have on the performance of a membrane unit. Insoluble materials tend to pile up in the concentration polarization layer, form

deposits on the membrane surface, and, in worst cases, may be directly absorbed on the membrane surface. Fats and lipids left in a process stream affect the flux in the same way that defoamers do and for this reason feed streams to membrane units are generally separated prior to processing.

The last form of process fouling that we have encountered is microbial fouling due to bacterial growth in the feed stream. In Table II we see a series of microbial counts done on the feed stream of an RO unit which always tended to foul heavily in the afternoon. It can be seen that counts in the feed stream and the concentrate stream show the presence of rapid growth in the unit. This type of growth tends to insolubilize protein and hence increases the amount of insoluble material in the unit in two ways. Protein becomes insoluble (aggregates) while the presence of a great many bacteria is also a source of insolubles. In addition, some bacteria have a tendency to attach themselves to surfaces and form tenacious fouling aggregates in the concentration polarization layer.

External Fouling

Surprisingly, all fouling does not take place on the surface of the membrane. We, very early in our efforts, found that membrane units are also susceptible

TABLE II. Microbial counts during processing

	Coliform count			Standard plate count		
Time	Feed	Conc.	Ratio	Feed	Conc.	Ratio
12:30	245	5,800	23.7	1.9×10^6	1.85×10^6	0.97
1:00	140	2,450	17.5	1.4×10^6	1.4×10^6	1.00
1:30	240	1,100	4.6	1.2×10^6	6.5×10^6	5.4
2:00	665	3,200	4.8	8.9×10^5	1.8×10^6	2.02
2:30	345	2,200	6.4	4.2×10^5	1.8×10^6	4.30
3:00	1,100	8,900	8.1	3.2×10^5	3.5×10^6	10.90
3:30	2,100	3,500	1.7	3.4×10^5	4.3×10^6	12.50
4:00	2,000	4,000	2.0	2.7×10^5	4.15×10^6	15.30
4:30	850	50,000	58.8	4.6×10^5	1.11×10^7	24.10
5:00	21,100	85,500	4.05	3.9×10^5	3.9×10^6	10.00
5:30	20,400	19,000	0.93	4.7×10^5	4.6×10^6	9.80

to fouling on the permeate side of the membrane. Generally, this type of fouling is caused by yeasts growing behind the membrane, in the membrane backing, and in other parts of the permeate system. To combat this type of fouling we developed Monarch Membrane Soak 40, a patented composition, which has eliminated this problem from most membrane units.

Some forms of membrane fouling are not related to process parameters or to any foulants in the feed stream. The major problem noted thus far has been the appearance of a black residue on many UF membranes. UF membranes, probably because of their high fluxes, are very sensitive to undissolved particulate matter. Most often this particulate matter can be traced to the water supply used for making up cleaning solutions and flushing the unit. In other cases, factors such as live steam injection for heating solutions may also have contributed to this problem. Since this soil is inert, the solution thus far has been to improve the water source used for the plant. Some plants which have both RO and UF units have stored permeate water and used it for flush and wash solution make up. Others have installed some type of water treatment system to improve the water supply.

Unit Characteristics

There are several different types of membrane units currently being sold to processers in the dairy industry. In Table III we have listed the suppliers of both RO membranes and equipment to the dairy industry. These units all have slightly different internal characteristics in both their UF and RO configurations. For the sake of briefness we have not included a similar list of UF suppliers but we would note tha Dorr-Oliver supplies a plate and frame UF unit while Romicon supplies a hollow fiber UF unit. In Table IV we have

TABLE III. Reverse osmosis suppliers

	Suppliers (equipment)	Suppliers (membranes)	Membrane types
Spiral wound	Ladish-Triclover	Osmonics	CA
	Thomas Technical	Abcor	CA
	Osmonics	DSI	CA, TFC
	Filt. Engineering	Filt. Engin.	CA, TFC
Plate & frame	Pasilac, Inc.	Pasilac	CA, TFC
		Hoechst	CA
Tubular	Damrow-PCI	Damrow-PCI	CA, TFC
	Abcor	Abcor	CA

TABLE IV. Unit problem areas

Tubular	Spiral	Plate & frame
All may exhibit growth in permeate system		
End caps soil	Seam areas soil	Rib areas retain soil
End gaskets soil	Module center soils	Entry and exit port areas soil
Shrouds hide growth	Interconnectors retain soil	End plates soil

listed the units by configuration and detailed some of the areas which have presented difficulties in the past. All in all we have found that most of the difficult forms of fouling seem to affect the units in roughly the same manner and that no configuration has a clear advantage in terms of either ease of cleaning or freedom from fouling.

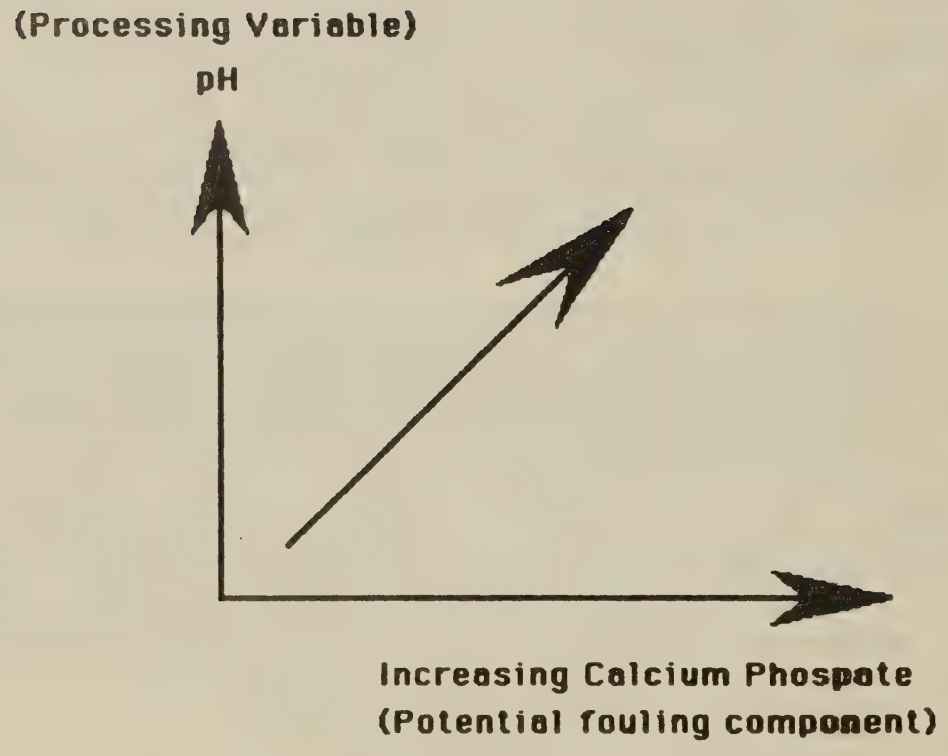
Fouling Interactions

We will now proceed to summarize the effects of the various factors on the fouling potential of the feed stream as noted in field installations. These relationships are diagrammed in Figures 10 and 11 and the explanation of the diagrams is given in Figure 9. In Table V we have summarized the various

TABLE V. Soil interactions

	Protein	Calcium phosphate	Fats lipids	Bacteria	Mold	Yeasts
Protein	++	++	+++	+++	N	N
Calcium phosphate		+	+	++	N	+
Fats-lipids			+	+	+	+
Bacteria				+++	+	++
Mold					+	+
Yeast						+++

Fouling due to Calcium Phosphate increases as the pH of the process fluid increases



The vertical axis designates a processing factor.

The horizontal factor designates a potential fouling component.

The arrow indicates how fouling due to an interaction between the processing factor and the fouling component is expected to increase.

Figure 9.

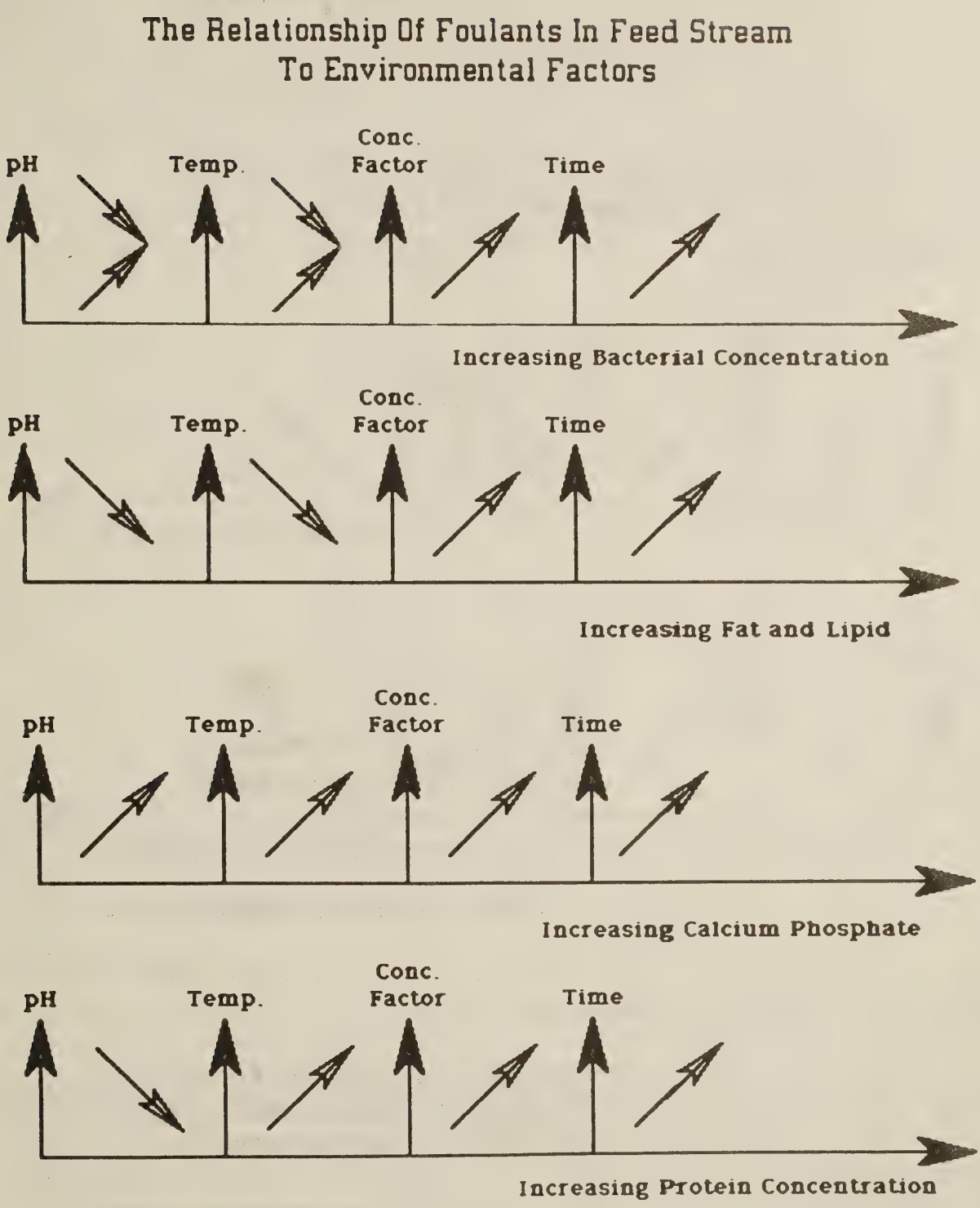

The Relationship Of Foulants In Feed Stream
To Environmental Factors
pH
Temp.
Conc.
Factor
Time
Increasing Bacterial Concentration
pH
Temp.
Conc.
Factor
Time
Increasing Fat and Lipid
pH
Temp.
Conc.
Factor
Time
Increasing Calcium Phosphate
pH
Temp.
Conc.
Factor
Time
Increasing Protein Concentration

Figure 10.

The Relationship Of Foulants In Feed Stream
To Environmental Factors

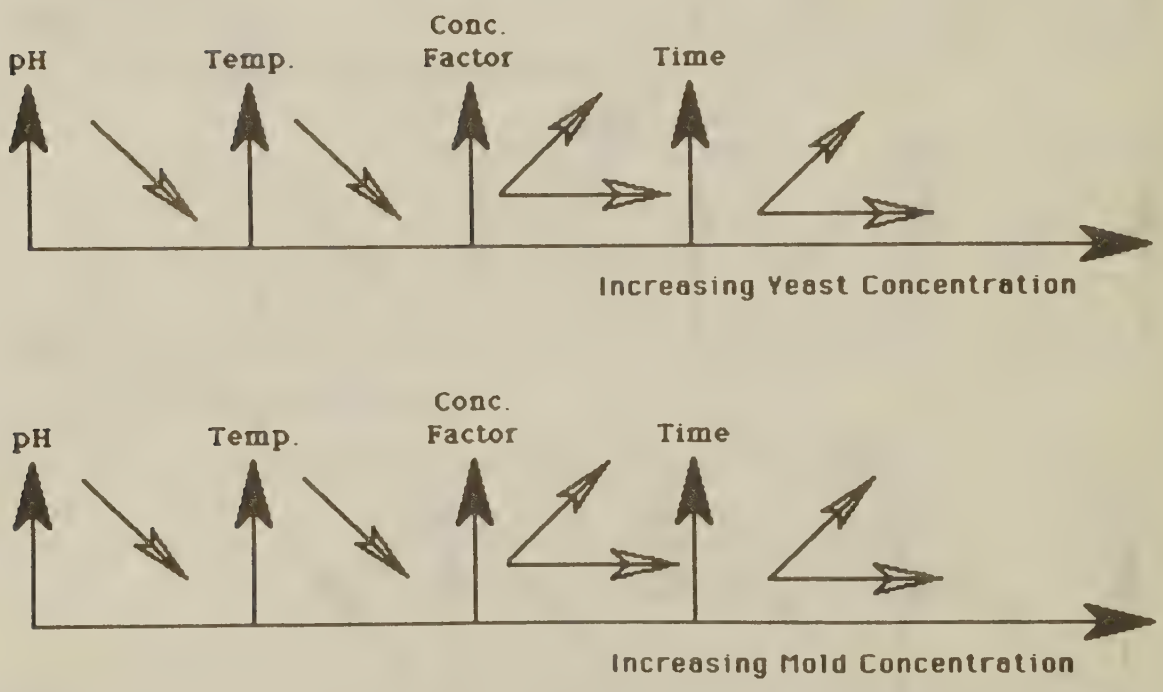


Figure 11.

types of interactions that we have noted among the various fouling components in the field. The most prominent and most dangerous interaction, in terms of the difficulty of removing a soil, is the presence of microbiological fouling and the interaction of the various soil components with microbial growth in the feed stream.

In Tables VI and VII we have displayed the various types of cleaning regimes that are currently being used on both RO and UF units in field installations today. A typical cleaning regime for a CA RO unit operating on whey is given

in Table VIII. A typical cleaning regime for a polysulfone UF unit is given in Table IX.

TABLE VI. Reverse osmosis units

Step	Time	Temp	pH	Comments
Flush	10-15 min	100-140°F (CA) (TFC)	Near neutral	Flush till exit water pH equals that of flush water
Acid	30 min	90-140°F (CA) (TFC)	About 2.0	Strong mineral acid
Alkaline	30-240 min	95-150°F (CA) (TFC)	7.0-12.5 (CA) (TFC)	CA membranes use enzyme cleaner while TFC membranes use non-chlorinated alkaline cleaners
Sanitation	5-30 min	Ambient to 170°F (CA) (TFC)	Near neutral	CA membranes use chlorine or iodine while TFC membranes use peroxide or high temperature

In Tables X and XI we have summarized the visual indicators of the most common types of fouling encountered in systems at present. It has been our experience that these visual cues can serve as a valuable aid in diagnosing the type of problem that a unit is having.

Cleaning Compounds

We would like to conclude with a few thoughts about the important factors in any cleaning method and the important properties of the compounds that are used. Any compound that is to be used in cleaning a membrane unit should have as many of the following properties as possible.

1. High active component concentration
2. Good solubility
3. Moderate foam levels
4. Compatibility with internal unit components
5. Good buffer system
6. Good stability

TABLE VII. Ultrafiltration units

Step	Time	Temp	pH	Comments
Flush	10-15 min	100-160°F (CA) (PS)	Near neutral	Flush till exit water pH equals that of flush water
Acid	30 min	95-150°F (CA) (PS)	About 2.0	Some manufacturers prefer nitric acid while others prefer phosphoric
Alkaline	30 min-indef.	100-160°F (CA) (PS)	8.5-13.0 (CA) (PS)	Alkaline washes on PS membranes vary widely in alkalinity, chlorine content and other variables
Sanitation	15-30 min	Ambient	Near neutral or acidic	Chlorine, iodine, or peroxide

NOTE: FLUSHES INTERVENE BETWEEN ALL UF CIP STEPS.

These points can be illustrated with several enzyme cleaners that are currently being sold for the purpose of membrane cleaning. In Figure 12 we see the level of enzyme activity present in these compounds. It has been our experience that cleaning with a product that has an adequate level of enzyme activity can lead to an average flux 5 to 15% greater than that obtained by cleaning with a product that has a low level of enzyme activity. In Figure 13 we see solutions of the same enzyme cleaners displayed. It can be seen that products B and D have turbid solutions at their use dilutions. This generally means that the product contains some components which are not fully soluble. Such insolubility is common in many laundry detergents used in the home since the size of the insoluble material is small enough to pass through fabric fibers. Such insoluble material, however, cannot pass through membranes where it may instead deposit on the membrane surface. The Monarch Enzyme 70 is the only one of these products which provides a solution pH in the range 7.0 to 7.5. The product labelled B provides a solution pH of 7.7 while the other products provide pH values above this range. Hence these products are not suitable for units which require cleaning at a near neutral pH. The Monarch Enzyme 70 product, however, because of some of its components is not compatible with all of the RO units on the market. Products B, D, and E suffer from this same type of incompatibility. Monarch markets a special product called Monarch Enzyme DDS which meets the needs of these particular units and overcomes the material incompatibility. This product, because it is buffered at a pH in the range 8.0-8.5, is in turn not suitable for those

TABLE VIII. Cellulose acetate RO plant

Step	Cycle	Using	Amount	pH	Time	Temp	Pressure	
1	Flush	Water/RO permeate		5.0-7.5	15 min	100°F max. (37.7°C)	5-9 Bar	
2	Enzyme	Monarch Enzyme DDS	20 lbs	8.0-8.5	90 min	100°F max. (37.7°C)	5-9 Bar	Check pH after 5 min
3	Flush	Water/RO permeate		5.0-7.5	15 min	100°F max. (37.7°C)	5-9 Bar	
4	Acid	Monarch Acid 23	1.5 gal	2.0-2.5	20 min	100°F max. (37.7°C)	5-9 Bar	Check pH after 5 min
5	Flush	Water/RO permeate		5.0-7.5	15 min	100°F max. (37.7°C)	5-9 Bar	
6	Soak	Monarch Soak 40	16 lbs	3.0-4.0	-	100°F max. (37.7°C)	20 Bar	Check pH after 5 min
7	Flush	Water		5.0-7.5	15 min	70°F max. (21.1°C)	20 Bar	Potable water only
8	Sanitize	Monarch Monoklor liquid	33 oz (50 ppm max.)	6.5-7.5	20 min	70°F max. (21.1°C)	20 Bar	Check pH chlorine level
9	Flush	Water		5.0-7.5	-	70°F max. (21.1°C)	20 Bar	Potable water only

units which require a lower pH. In general, one finds these same small but significant differences with polysulfone UF membranes and the new generation of thin film composite RO membranes.

These are the general types of problems that one encounters in the selection of cleaning agents for all membrane systems. Some products have low active concentrations, some products give turbid solutions at use dilutions, some products have incompatibilities with internal unit components, some products give the wrong pH, and we have even seen some products offered for salt which

TABLE IX. Polysulfone UF plant

Step	Cycle	Using	Amount	pH	Time	Temp	Comments
1	Flush	Water		5.0-8.0	15 min	100°F	
2	Acid	Monarch Membrane Acid 23	2.5 gal	1.9-2.3	30 min	120°F	Monitor pH
3	Flush	Water		5.0-8.0	15 min	100°F	
4	Alkaline	Monarch Filter-pure 120	3.0 gal	11.4-12.0	60 min	130°F	Monitor pH and maintain 120 ppm chlorine
5	Flush	Water		5.0-8.0	15 min	100°F	
6	Sanitize	Chlorine	16 oz	5.0-7.0	20 min	Ambient	Maintain 100 ppm chlorine

TABLE X. Calcium phosphate fouling

Soil responds well to acid
Soil is fine and gelatinous
Soil is not sticky or tacky

Permeate system fouling

Soil has a yeasty odor
Soil is yellow-brown in color
Soil has a low pH
Soil can be thick and fuzzy
Yeast and mold counts high in permeate

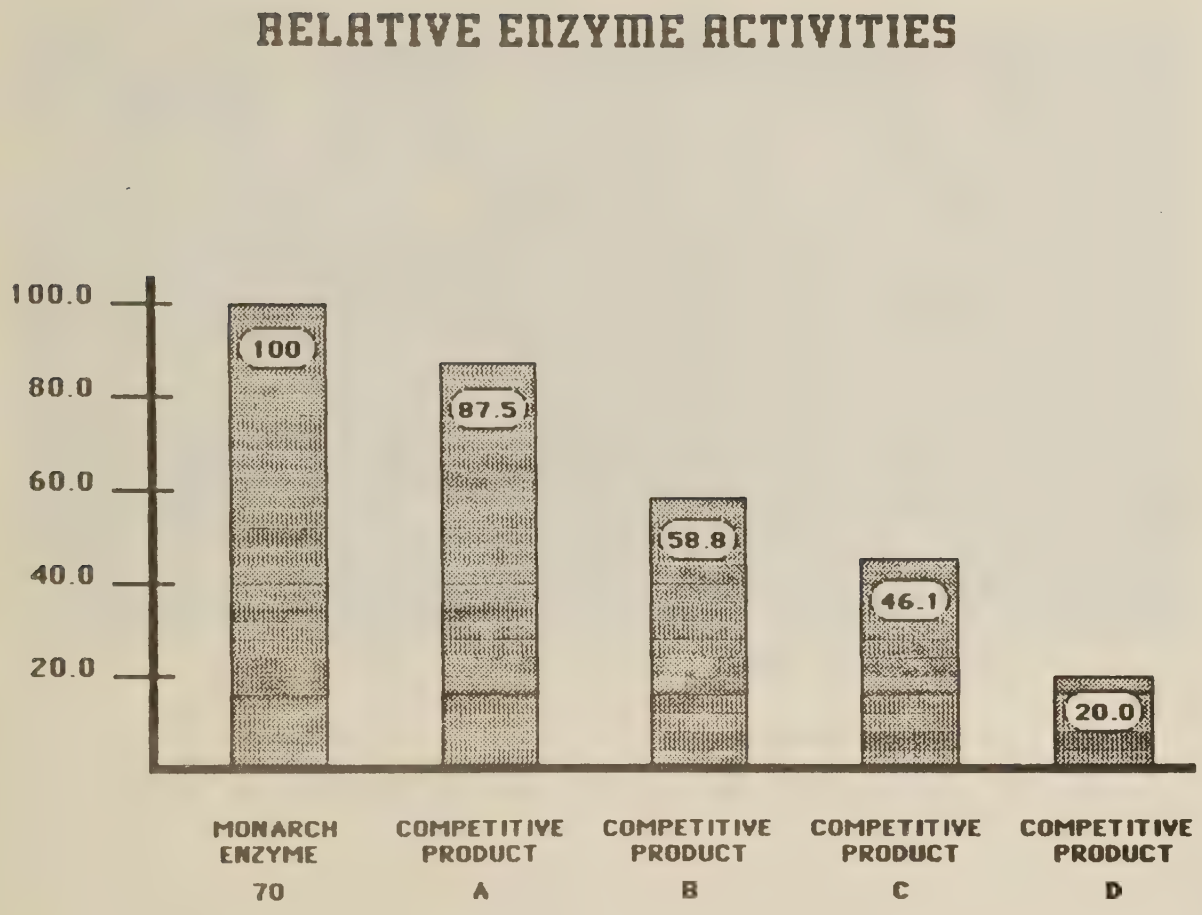


Figure 12.

do not have adequate stabilities. The question of internal component compatibility has forced some equipment and membrane manufacturers to establish lists of approved cleaners which serve as a protective screen for their units. Membrane manufacturers have also published pH and temperature requirements for their units and these can also serve as guidelines in the selection of cleaning compounds. Compounds that have met the manufacturers' approval, however, have not been screened for active levels, stability, or quality. Hence the final selection of a cleaning compound rests on the reputation of the manufacturer of the compound and the quality of the raw materials that he uses in compounding his products.

TABLE XI. Concentrate side bacterial fouling

White film on stainless steel
Soil may appear thick and puffy on CA membranes
Soil may appear thin and translucent
Soil feels sticky or tacky
Soil can be filamentous in appearance
Extraneous fouling
Soil is dark—often described as oily in appearance
Prefilter may have dark cast or dark spots
Soil is high in Iron or Silica
Dark brown

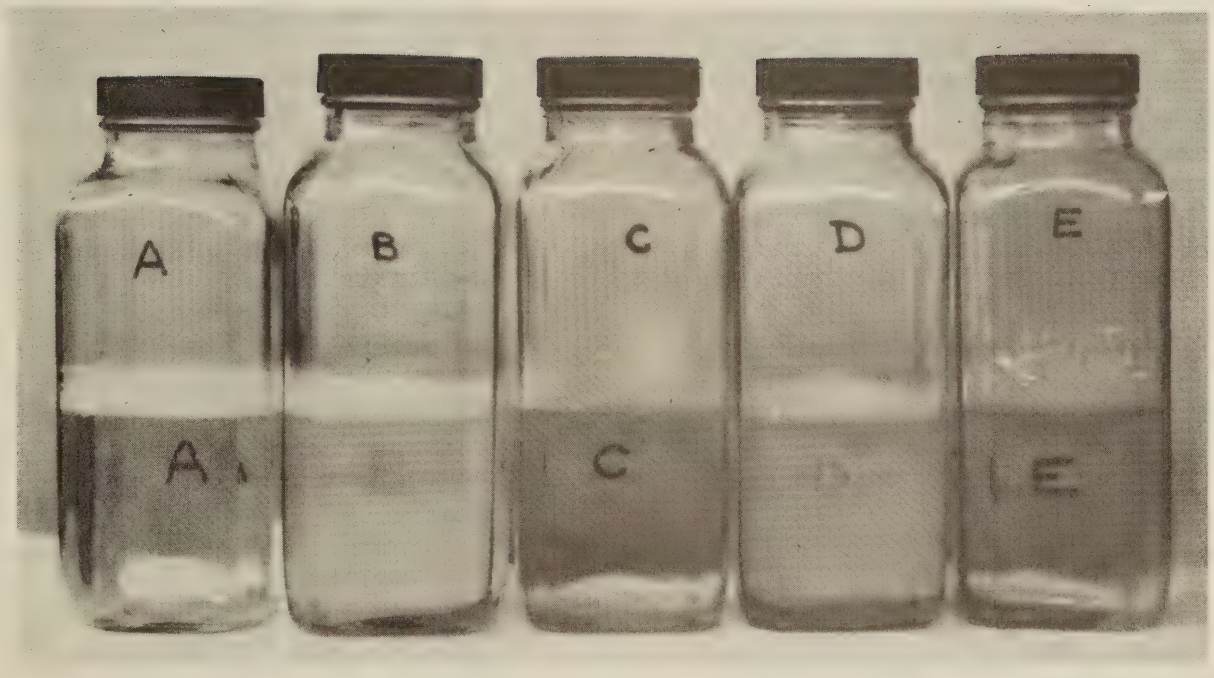


Figure 13.

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